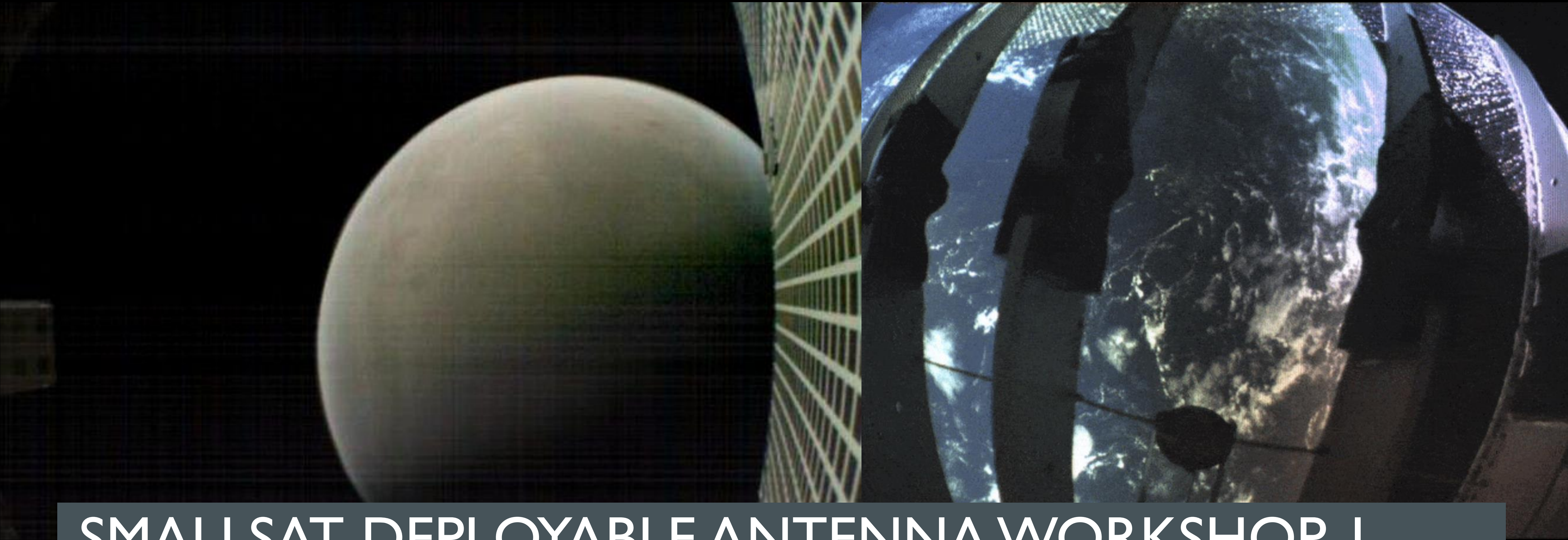


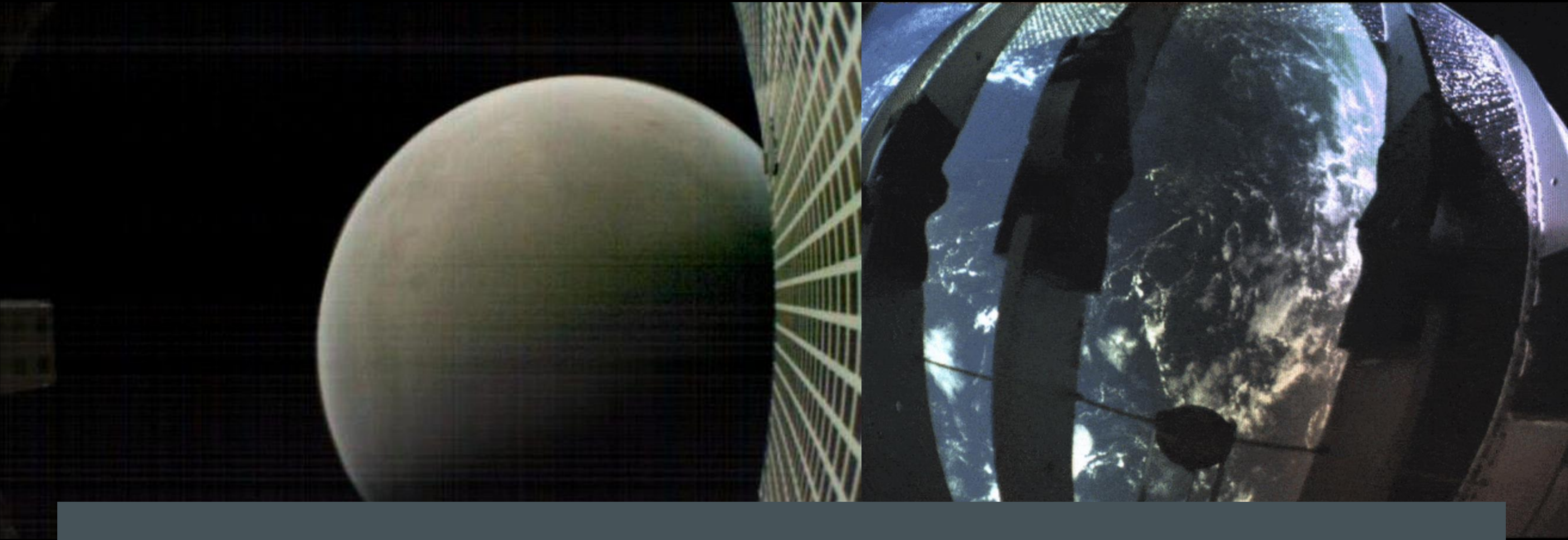
# SMALLSAT DEPLOYABLE ANTENNA WORKSHOP 1

JONATHAN SAUDER, JASON HYON, MARK HAYNES, KEN COOPER, RAQUEL RODRIGUEZ MONJE, ROBERT BEAUCHAMP, SHANNON BROWN, PAULA BROWN, RICHARD HODGES, DANIEL BRODERICK, CAROL LEWIS

Jet Propulsion Laboratory, California Institute of Technology



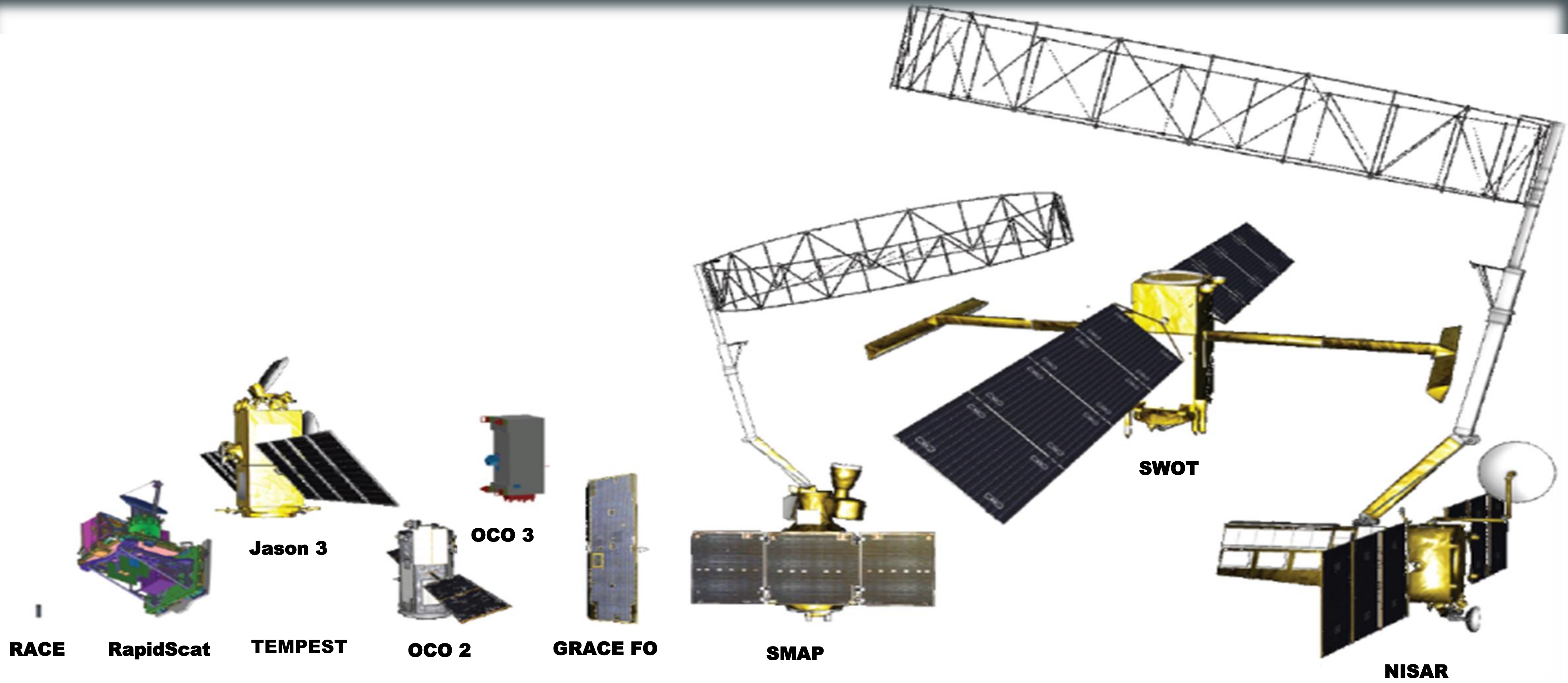
Jet Propulsion Laboratory
California Institute of Technology



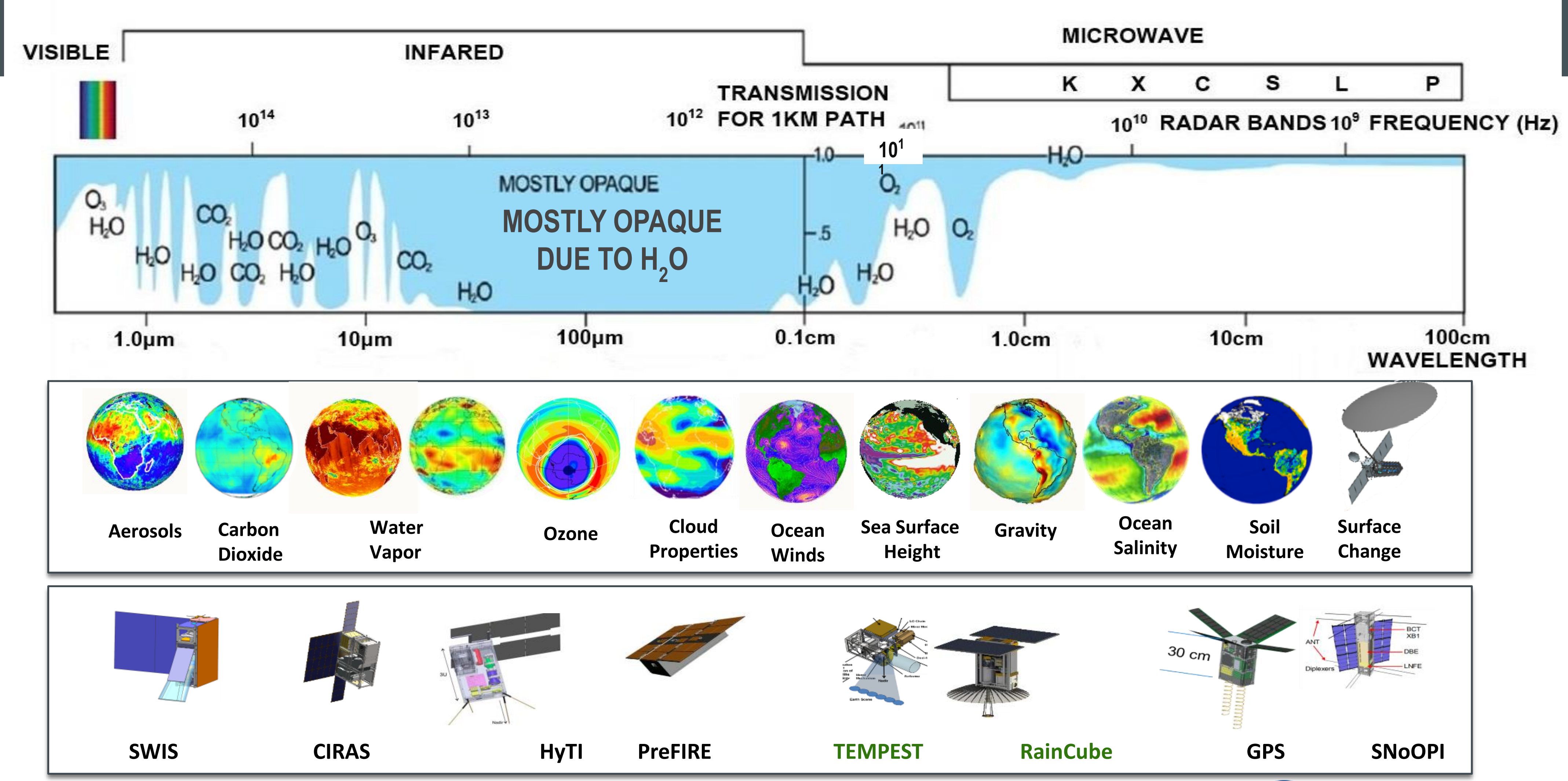
# A WELCOME FROM JASON HYON

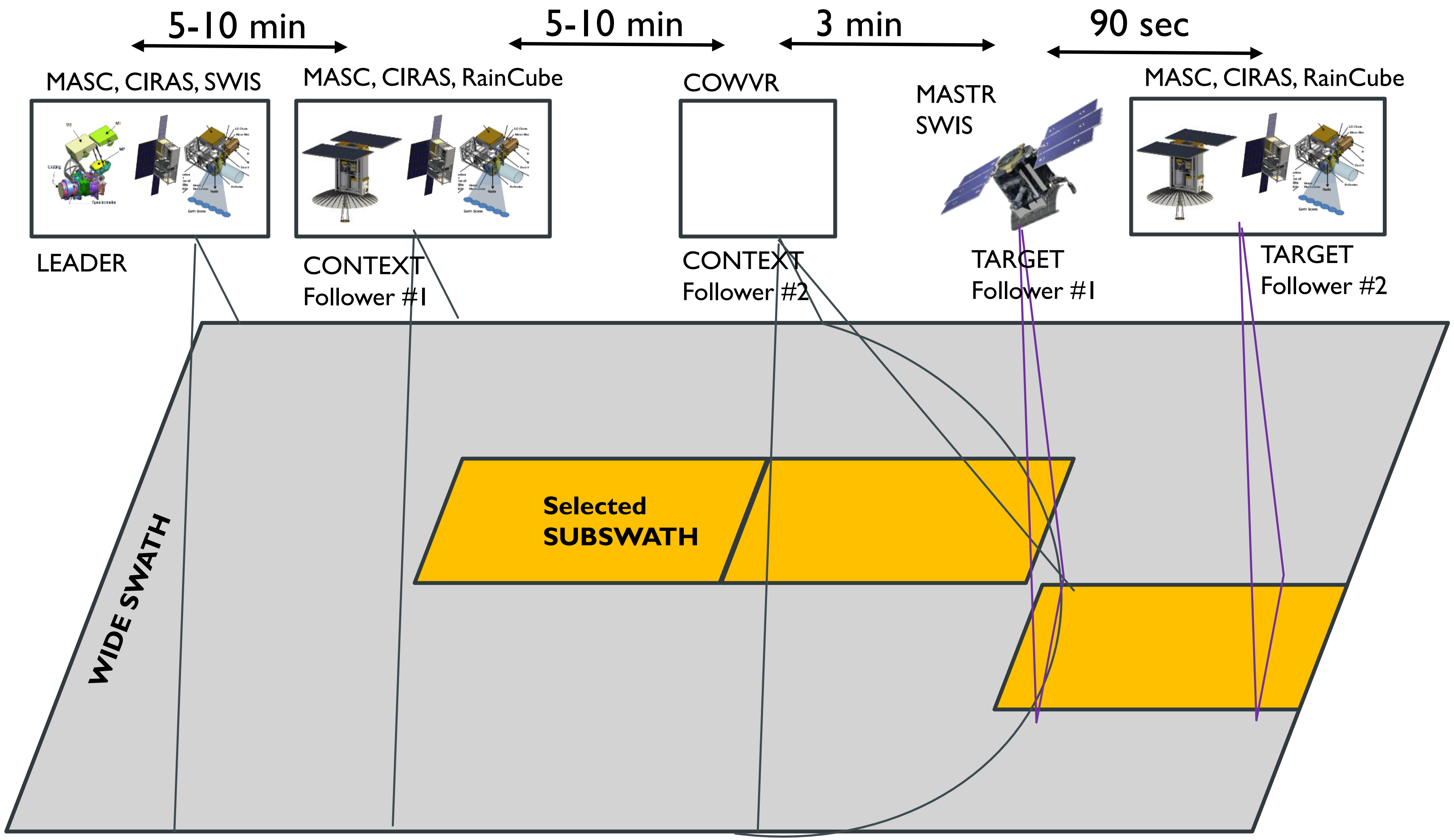
EARTH SCIENCE & TECHNOLOGY DIRECTORATE - CHIEF TECHNOLOGIST

# ALL DIFFERENT SIZES ARE NEEDED – POWER AND SWATH

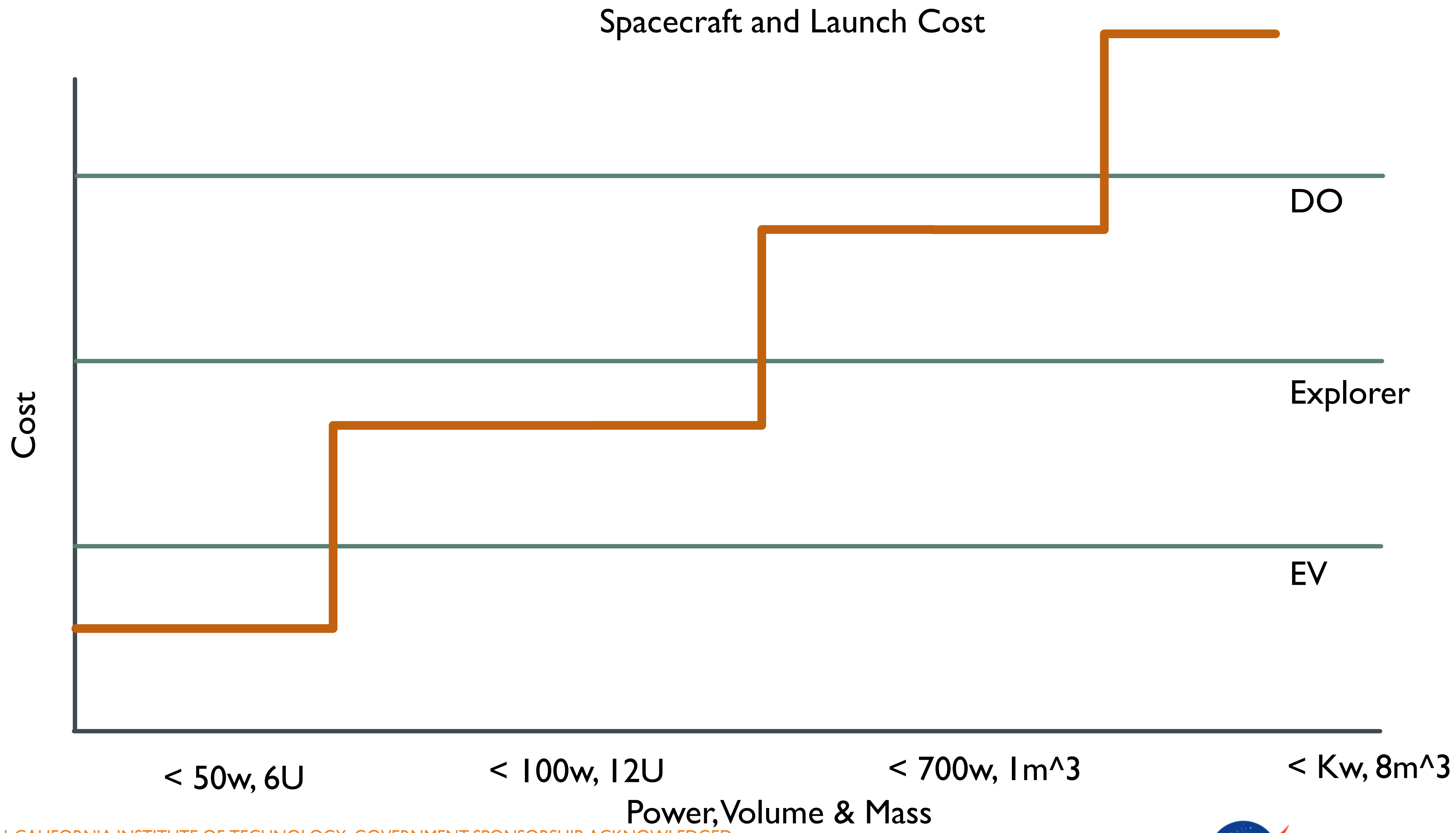


# Seeing Earth in a New Way at JPL






Note: SWIS and RainCube on Leader and Contex Follower #1 cover only their respective nadir portions of the wide swath


Spacecraft and Launch Cost
Cost
DO
Explorer
EV
< 50w, 6U
< 100w, 12U
< 700w, 1m^3
< Kw, 8m^3
Power, Volume & Mass

# AGENDA FOR WORKSHOP MEETING 1

| Time | Person | Description | Start Time |
|---|---|---|---|
| 15min | Sauder | Overview/Agenda | 8:30 AM |
| 45min | Haynes/ Cooper/Rodriguez Monje/ Beauchamp/ Brown | Instrument Aspirations | 8:45 AM |
| 15min | P. Brown | Overview of Current JPL Antenna Capabilities | 9:30 AM |
| 20min | Sauder | Current Technology Gaps for Mission Needs | 9:45 AM |
| 20min | Hodges | Derived Antenna Requirements | 10:05 AM |
| 30min | Group | Technical Question and Answer | 10:25 AM |
| 10min | | BREAK | 10:55 AM |
| 20min | Hyon | Funding Mechanisms and the Make vs Buy Decisions at JPL | 11:05 AM |
| 20min | Broderick | Technology transfer opportunities with JPL | 11:25 AM |
| 30min | Lewis | How to propose SBIR’s for solutions to the gaps | 11:45 AM |
| 5min | Sauder/Hodges | Who to talk to at JPL. Finding the right SME | 12:15 PM |
| 10min | Sauder | Next Steps for Continuing the Conversation with JPL | 12:20 PM |
| 30min | Group | Programmatic Question and Answer | 12:30 PM |
| **4.5hours** | **Total Time** | | |

# OVERVIEW/AGENDA

SMALLSAT DEPLOYABLE ANTENNA WORKSHOP

Jet Propulsion Laboratory
California Institute of Technology

# OVERARCHING WORKSHOP SERIES OUTCOMES

- Develop relationships with potential collaborators and suppliers for future proposals, for both technology development and/or flight projects, i.e. *partnership development*.
- Help potential outside collaborators/technologists/engineers/suppliers develop an understanding of key JPL instrument/space mission gaps related to deployable antennas.
- Help JPL scientists and instrument Principal Investigators (PI's) and team members understand deployable antenna technologies that are potentially available for their mission concepts.

# TWO SETS OF MEETINGS

- Today: Workshop Meeting 1
  - Goal 1: Communicate current JPL understanding of technology gaps and requirements associated with deployable antennas for SmallSats
  - Goal 2: Communicate ways potential partners can collaborate with JPL.
  - Attendees: JPL → Potential Partners
- June 2nd to June 18th: Workshop Meetings 2
  - Goal: Have potential partners present their capabilities to JPL, and discuss mechanisms for evolving the technologies to meet JPL needs.
  - Attendees: One Potential Partner → JPL (per meeting)
    - Each potential partner with relevant technologies meets separately with JPL

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# AGENDA FOR WORKSHOP MEETINGS 2

| Presenter | Description |
|---|---|
| Sauder | Overview/Introductions |
| Outside Organization | Presentation on Capabilities, and Relevance to JPL |
| ALL | Q&A & Discussion |
| JPL Panel | Formal Feedback from JPL |
| ALL | Ask Us Anything Style Session |

Time will be scaled pending feedback from the partner, and relevance to current missions.

# AGENDA FOR WORKSHOP MEETING 1

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# SMALLSAT DEPLOYABLE ANTENNA WORKSHOP
# SOLAR SYSTEM SMALL BODIES INSTRUMENT ASPIRATIONS

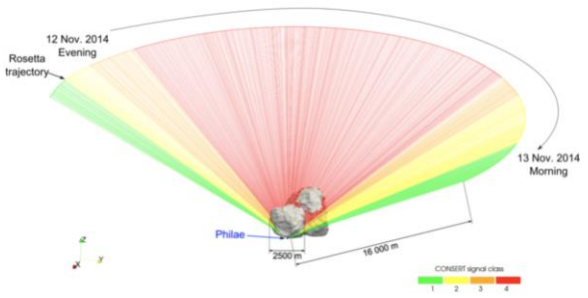
MARK HAYNES

Jet Propulsion Laboratory
California Institute of Technology

# SOLAR SYSTEM SMALL BODY RADAR MISSIONS

- The goal of small body radar missions is to probe and map the interior structure of comets and asteroids using low-frequency radar (5-100 MHz) using 3D SAR, transmission measurements, or inverse scattering techniques.
- To date, only one mission has preformed radar measurements of a comet: Rosetta-CONSERT at comet 67P/C-G (center 90 MHz, BW 8 MHz)
- Future radar instruments of this type are looking at monostatic and bistatic geometries on smallsat and cubesat platforms.
- Antennas for low-frequency radar sounders have historically been some kind of deployable dipole (tape, stacers, dipole or folded-dipole, boom/truss-deployed)

CONSERT PROBES THE NUCLEUS OF COMET 67P/C-G




Date: 30 July 2015
Satellite: Rosetta
Copyright: ESA/Rosetta/Philae/CONSERT

# WHAT WE'RE LOOKING FOR

- Compact deployable antennas in cubesat and smallsat form factors.
- We would like >=20% fractional bandwidth at center frequencies between 5 and 100 MHz, with reasonable efficiency (80-90%). Reusable designs if we change the center frequency.
- We are interested in dual-band options: e.g., 5 and 15 MHz, or 20 and 60 MHz, where each center frequency has its own band. If a single antenna structure can do this (e.g., over-moded), that is preferable to multiple independent antennas.
- Feasibility studies of UWB traveling wave antenna designs with good time domain responses, e.g., deployable Vivaldi rather than log-periodic. Antennas that can operate as high as 100 MHz but as low as possible (physically large) without the antenna size and mass overwhelming smallsat control systems.
- Radiation tolerant designs that minimize or avoid the use of dielectrics, and that can meet performance in cold deep space but survive a hot Venus flyby.
- Note, at these frequencies, antenna-spacecraft coupling makes the spacecraft part of the antenna, which can have a significant impact on design and performance considerations.

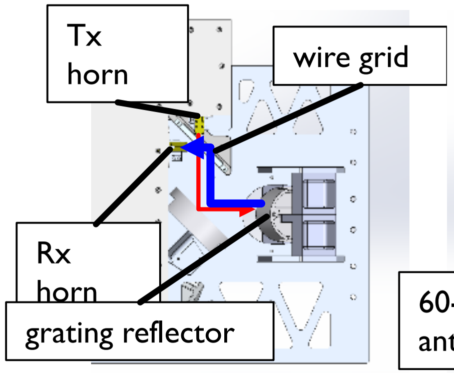
# VIPR: SHORT INSTRUMENT OVERVIEW AND VISION FOR SPACE

KEN COOPER

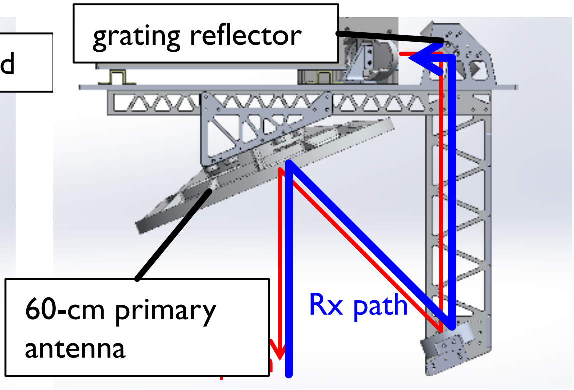
Jet Propulsion Laboratory
California Institute of Technology

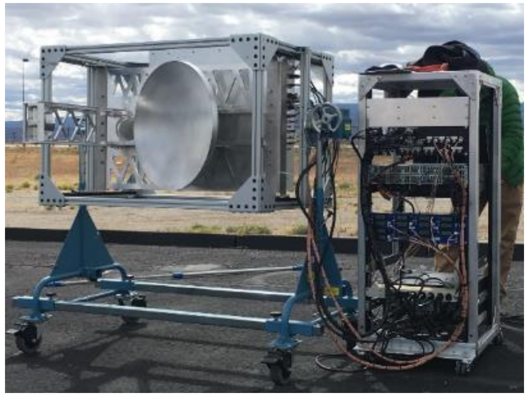
# Ground/Airborne VIPR Architecture and Hardware

*top view*



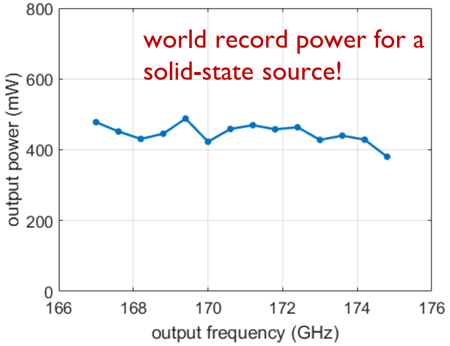

*side view*

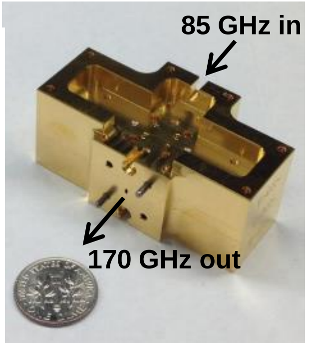


| VIPR Radar Parameter | Value |
|---|---|
| Radar frequency | 167-174.8 GHz |
| Transmit power (FMCW) | ~300 mW |
| Antenna gain | 58 dB |
| Noise figure | ~8 dB |
| Range resolution | 15 m |
| Detection noise bandwidth | 1 kHz |
| single-chirp dBZ$_{min}$ at 1 km range | -40 dBZ |

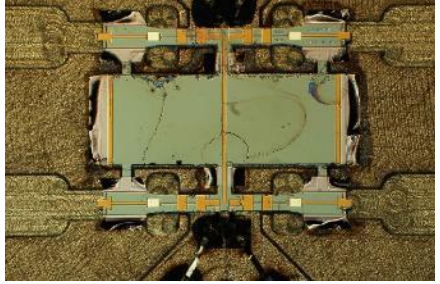
**High output power G-band sources**




*split-waveguide block pump plane*

*four-way 170 GHz doubler chip*




Ken B. Cooper, et al., “A G-Band Radar for Cloud and Humidity Remote Sensing,” *IEEE Transactions on Geoscience and Remote Sensing*, 2020.

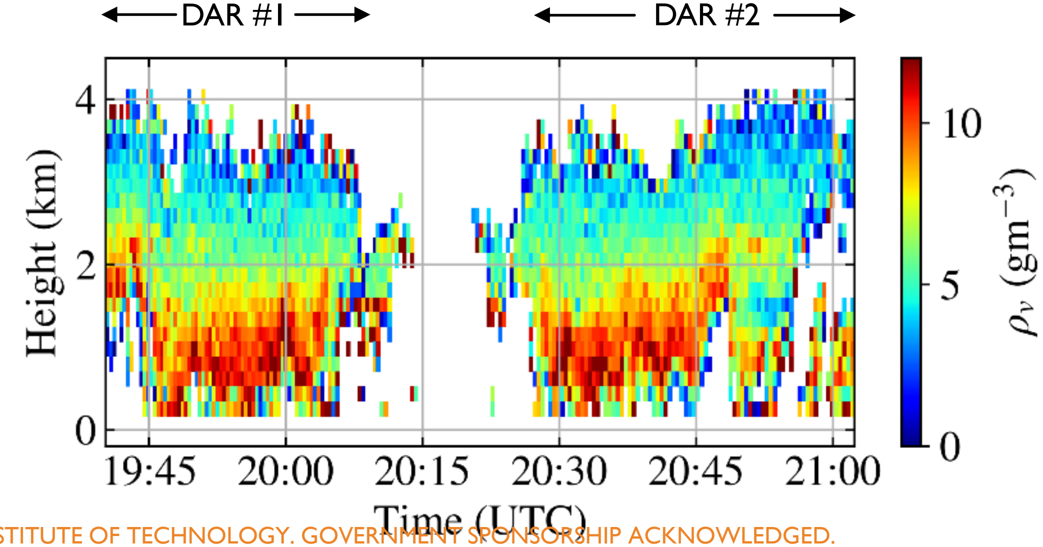
Jose Siles, et al., “A New Generation of Room-Temperature Frequency Multiplied Sources with up to 10x Higher Output Power in the 160 GHz - 1.6 THz Range,” *IEEE Transactions on Terahertz Science and Technology*, 2018.

# 2019-2020 VIPR Airborne Campaign (IIP-16)

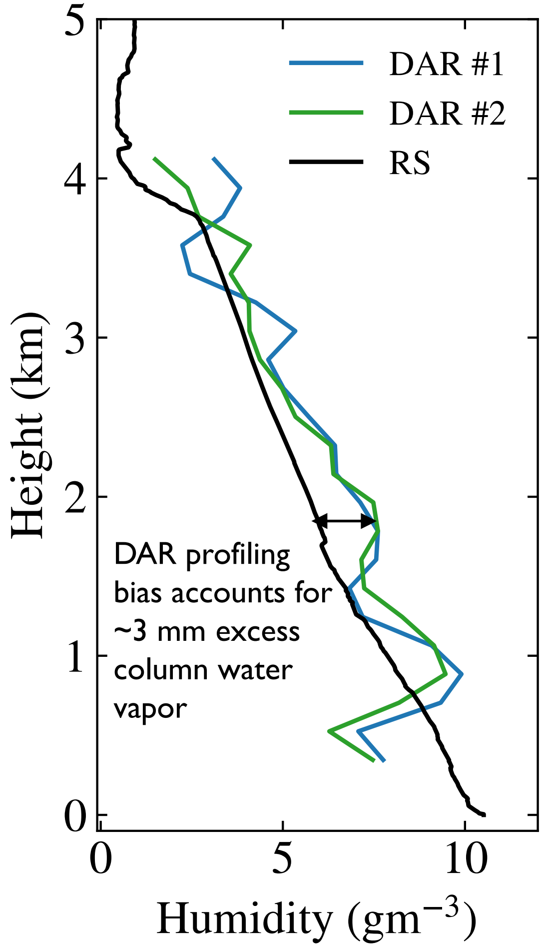
Ken B. Cooper, et al., "A G-band Radar for Humidity and Cloud Remote Sensing," IEEE Transactions on Geoscience and Remote Sensing, 2020.

Roy, Richard J., et al. "Validation of a G-band differential absorption cloud radar for humidity remote sensing." Journal of Atmospheric and Oceanic Technology, 2020.


**VIPR water vapor retrievals**




**Comparing time-averaged VIPR profiles to radiosonde**



# Space VIPR: Need ~10x larger-area antenna (2 meter diameter)

Such a large antenna is possible by following the examples of CloudSat and the Microwave Limb Sounder:

Im, Eastwood, Chialin Wu, and Stephen L. Durden. "Cloud profiling radar for the CloudSat mission." In *IEEE International Radar Conference, 2005.*, pp. 483-486. IEEE, 2005.

Figure 4: CPR Antenna Subsystem flight model.

Figure 5: The integrated CPR and CloudSat spacecraft bus flight unit.

Cloudsat antenna:
- 1.85 m diameter
- composite graphite to reduce mass
- 94 GHz narrowband operation
- 63 dBi gain
- offset-fed parabola
- no scanning

Cofield, Richard E., and Paul C. Stek. "Design and field-of-view calibration of 114-660-GHz optics of the Earth observing system microwave limb sounder." *IEEE transactions on geoscience and remote sensing* 44, no. 5 (2006): 1166-1181.

Fig. 7. GHz Module in the Near-Field Range for definitive FOV calibration after environmental tests. The camera was near theodolite station 2 in Fig. 6.

EOS-MLS antenna:
- 1.6 m x 0.8 m diameter
- egg-crate interior with graphite epoxy skin for good thermal stability
- 240 & 640 GHz operation
- 9.8 micron rss surface roughness (and profile?), which is lambda/50
- offset-fed parabola
- mechanized scanning over 12°

# Space VIPR Vision: Basic Antenna Specifications

| | |
|---|---|
| Frequency of operation: | 155-175 GHz |
| Diameter: | 2 m |
| Surface accuracy: | $\lambda/40$ preferred (42 microns or 2 mils), and 2x worse possibly acceptable |
| Geometry: | center-fed (Cassegrain) or offset-fed parabola |
| Scanning capability: | ±1.5° (±25 beam widths or ±10 km on the ground) is very helpful and compelling, but not required; scanning would likely require motorized actuation of a feed reflector subassembly |
| Antenna deployment: | Preferred to maximize flight options and opportunities |
| Mass/volume: | Low mass/volume is a priority; use CloudSat and MLS as baselines |
| Orbit: | Low earth orbit |

# COMPACT CLOUD AND PRECIPIATION RADARS

RAQUEL RODRIGUEZ MONJE

Jet Propulsion Laboratory
California Institute of Technology

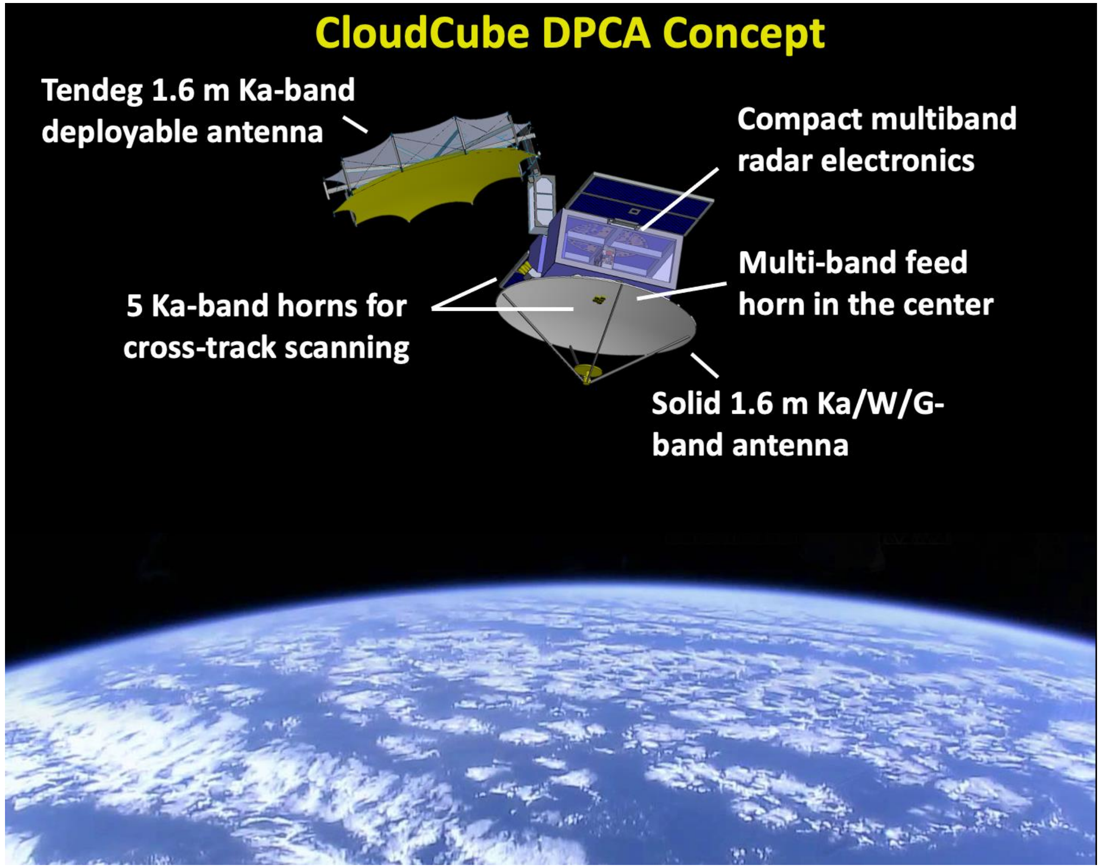
# COMPACT CLOUD AND PRECIPITATION RADARS

- RainCube (Radar in a CubeSat), developed at JPL, was the first of this kind of instruments to successfully demonstrate, in space, a Ka-band radar within a 6U CubeSat along with a 0.5 m deployable mesh reflector

- Building-off the technical success of RainCube, we are developing, also at JPL, a new atmospheric multifrequency profiling radar, called CloudCube.

- Compact, affordable radar instruments facilitate the use of constellations of identical instruments flying in Low Earth Orbit (LEO) to observe the evolution of weather processes with high-vertical resolution profiling capabilities or in diverse orbits to increase sampling across the diurnal cycle.

# CLOUDCUBE




- CloudCube is been developed under the NASA ESTO Instrument Incubator Program (IIP).
- CloudCube combines 3-band radar electronics, using a minimalistic architecture that vastly reduces mass, power and size, development time and recurring cost.
- For the first time, CloudCube combines Ka-, W- and G-band (35/94/238 GHz, respectively) radar backscatter with Doppler velocity measurement capability at Ka-band to simultaneously observes key components of a variety of atmospheric processes;
- CloudCube instrument design is modular allowing for selection of different subsets of the radar frequencies to meet targeted mission observables from a resource-limited platform.

# CLOUDCUBE – SYSTEM PERFORMANCE

## Radar Parameters

| | Ka-Band | W-Band | G-Band |
|---|---|---|---|
| Fc (GHz) | 35.75 | 94.05 | 238 |
| TX Power (W) | 10 | 40 | 1 |
| NF (dB) | 3 | 4 | 7 |
| PRT (us) | 250 | 1600 | 1600 |
| Int Time (ms) | 67 | 200 | 200 |
| Altitude (km) | | 400 | |
| Velocity (m/s) | | 7600 | |
| Ant Diameter (m) | | 1.6 | |
| Ant Gain (dB) | 54 | 62.4 | 70.5 |
| Pulse Length (us) | 60 | 120 | 120 |
| Bandwidth (MHz) | 1.325 | 0.85 | 0.85 |
| Resolution 3dB (m) | 136 | 235 | 235 |
| Zmin (dBZ) | **2.5** | **-21.1** | **-16.9** |

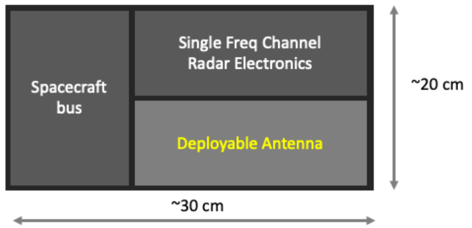
- The design of the electronics is constrained to mature solid-state components integrated in a compact architecture compatible with SmallSat accommodations.
- Such demanding power consumption and mass requirements set tight constrains on the radar design to meet the science requirements.
- CloudCube baseline instrument grants a minimum sensitivity of 2.5, -21 and -17 dBZ at Ka-, W- and G-band using a 1.6 m antenna.

# CLOUDCUBE POTENTAIL SPACECRAFT ACCOMMODATION

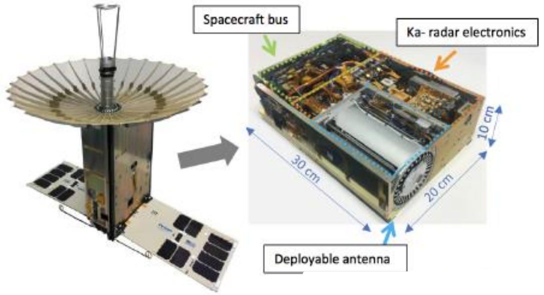
- ## CubeSat:

Single frequency radar configuration, reducing the instrument complexity, size, power and mass.

Stow volume < 3U.
Antenna diameter: 0.5 - 1 m
Funding opportunities: Tech demo, NASA/InVEST.




Notional CloudCube's footprint



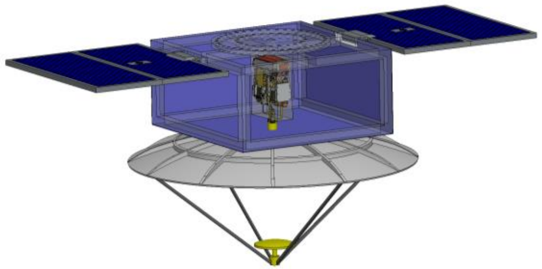

RainCube 6U

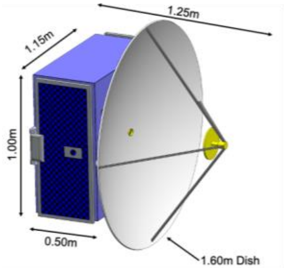
- ## SmallSat

With the current state of the art, CloudCube could be deployed only as part of a SmallSat payload with a standard solid reflector.

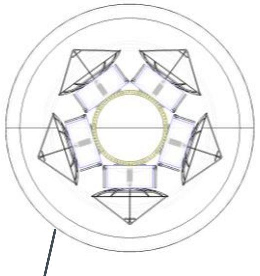
Reduce the cost of the mission by using hosted payload if we could reduce the mass and volume of the antenna (NASA InVEST, EVs).

Stow volume 4 - 6U.
Antenna diameter: 1.6 - 2.1 m
Funding opportunities: NASA/InVEST, EVs.






CloudCube in a notional ESPA Platform



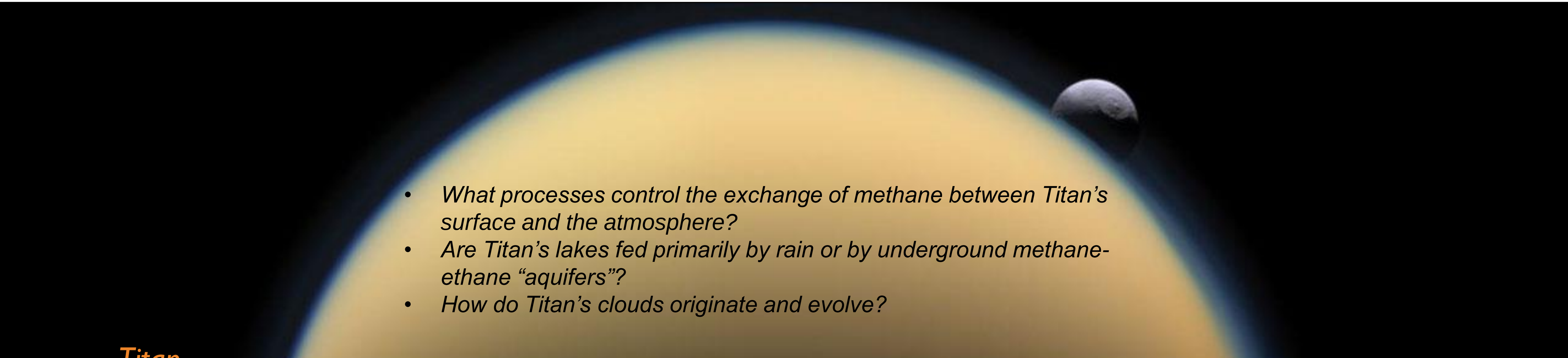
Spacecraft configuration on an ESPA inside a Falcon 9 5.2 m fairing

# RADARS FOR PLANETARY MISSIONS

Similar technology used on Earth observations can be used for planetary exploration.

A millimeter-wave radar can penetrate through Titan's optically opaque atmosphere to provide:

1. Cloud/Precipitation radar: global information on the vertical structure of methane clouds and rainfall
2. Altimeter: global topographic map of Titan

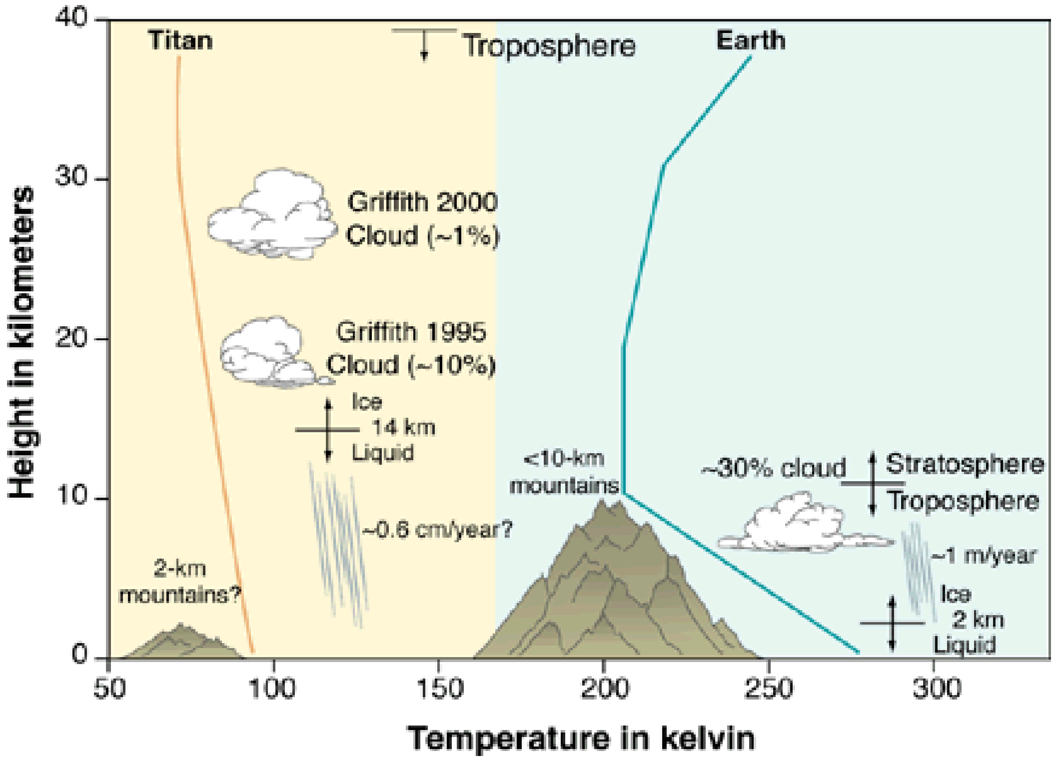


# RADARS FOR PLANETARY MISSIONS

- Titan comes with its own challenges for radar observations:
  - Larger range (Titan atmosphere is 40 km deep)
  - Large atmospheric attenuation (3 and 8 dB at Ka and W-band)
  - Reduction in methane reflectivity relative to liquid water

- Need of large antenna gain, hence, a dish reflector with a diameter of 2-4 m long.

- Need of light-weight to make it compelling for Planetary Science application which typically have stringent size, weight and power requirements



# ICE AND SUBSURFACE SOUNDING RADAR

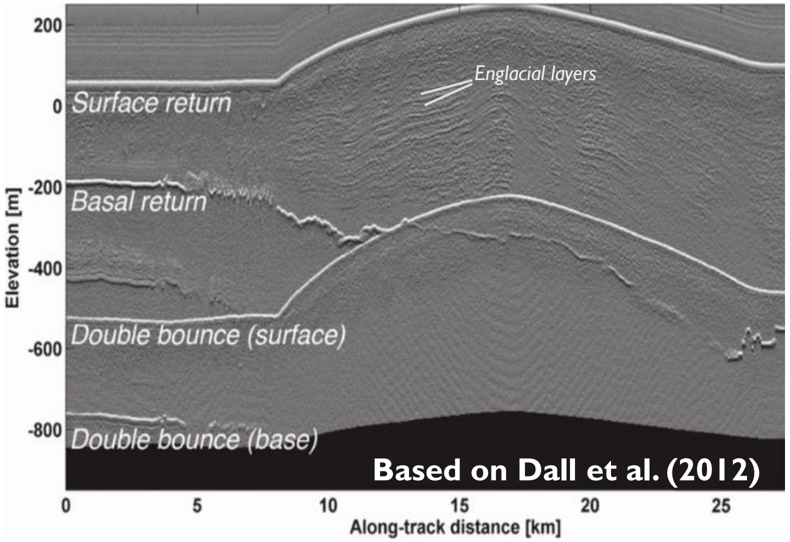
ROBERT BEAUCHAMP

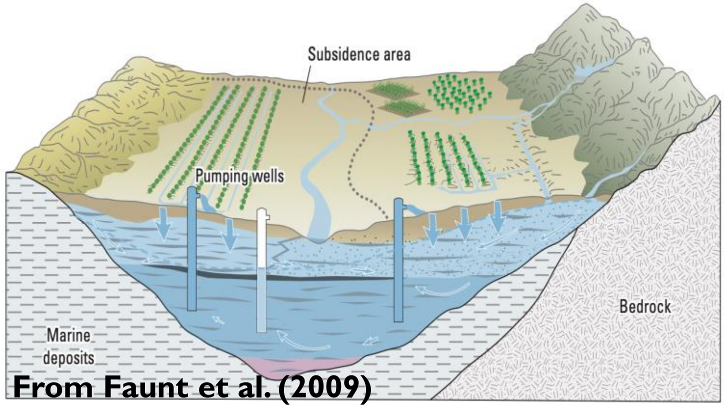
Jet Propulsion Laboratory
California Institute of Technology

# DISTRIBUTED ELEMENT RADAR BEAMFORMER FOR ICE AND SUBSURFACE SOUNDING

- Desire a large antenna aperture to unambiguously localize and detect subsurface echoes from the features we're interested in and reject unwanted surface clutter
- Long wavelength (45 MHz is 6.7 m) results in large antenna apertures (100's m to multiple kms) to achieve surface footprints on order of kilometers from LEO
- Use a sparse beamforming array to synthesize a high directivity aperture for VHF (40-50 MHz) and potentially with the addition of UHF (approx. 430-440 MHz)
- Technical challenges are low-cost, deployable wideband antennas and the synchronization of distributed elements to achieve a phase coherent apertures

# SOUNDER SCIENCE AND APPLICATIONS



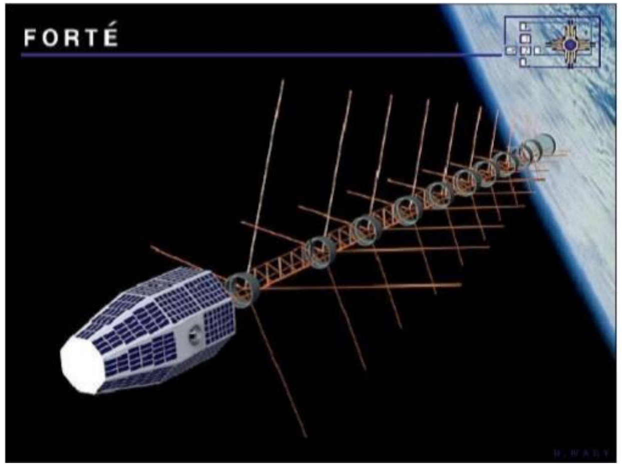




- **Ice sheet sounding measurements**
  - bed topography (ice thickness)
  - Basal condition (melting or frozen)
  - englacial layers and ice fabric structure (indications of historical flow)

- **Arid-Region Subsurface sounding**
  - Detection of groundwater and its distribution
  - Map the depth to the top of aquifers

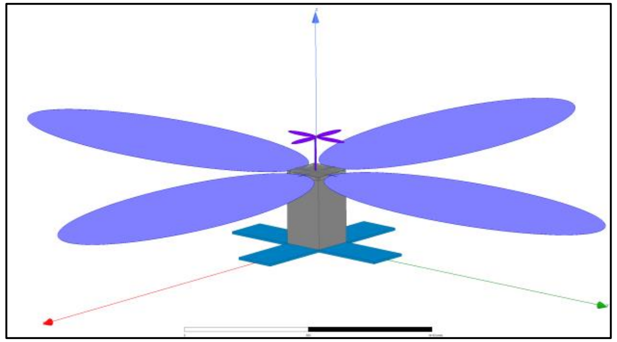
# IMPLEMENTATION CONCEPT

- A mothership with the transmitter and N RX-only daughterships in formation
  - Other concepts use daughterships with both TX and RX
  - Use SAR processing in the along-track direction
  - Use electronic beamforming in the across-track direction
- Deployable, wide-bandwidth VHF antennas are a challenge
  - Operating band: 40-50 MHz (i.e., 10 MHz bandwidth)
  - 10W (daughterships) to 100W (mothership) TX power
  - Dual-Polarization
  - Cubesat and SmallSat deployables
  - Antenna/ADCS dynamic interactions must ensure stable pointing




**Mothership Concept**

- VHF Transmitter and Receiver
- Small-Sat with deployable crossed dipole Yagi

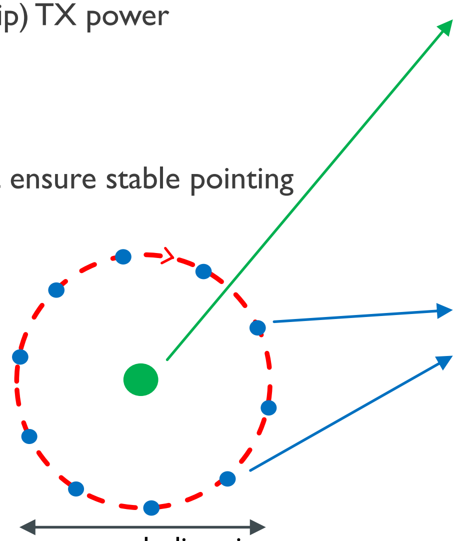


**Daughtership Concept**

- VHF Receiver
- Cubesat (12U shown) with deployable crossed dipole

**Notional Array Configuration**

Single Mothership
Many Daugtherships



# MECHANICALLY IMAGING MICROWAVE RADIOMETER SYSTEMS

SHANNON BROWN

Jet Propulsion Laboratory
California Institute of Technology

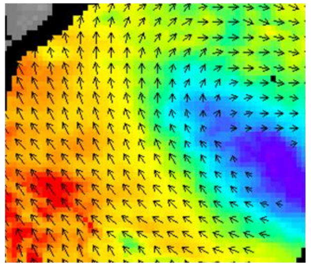
# TYPICAL MW-RADIOMETER PRODUCTS

ACCP
PBL
Air-Sea Flux

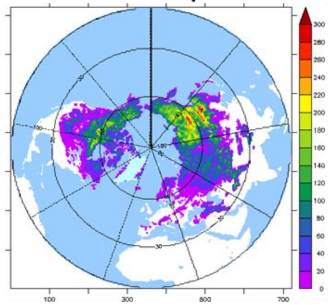
Ocean wind vector
T/q sounding

Ocean wind vector
Tropical Cyclone Intensity
T/q sounding
Sea ice characterization

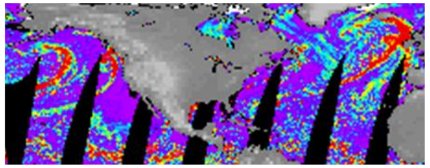
Ocean Surface Wind Vector



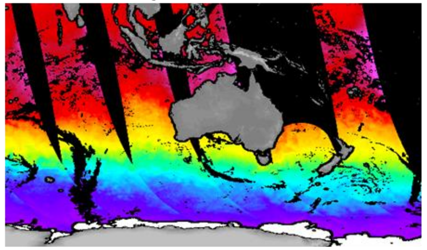
Snow Water Equivalent



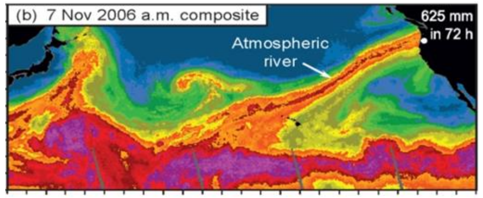
Cloud Liquid Water



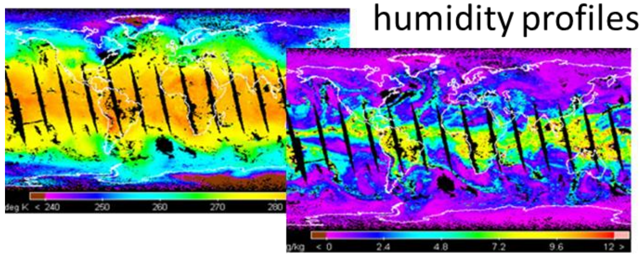
Sea surface temperature



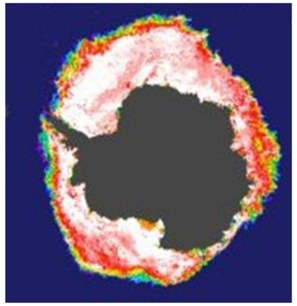
Precipitable Water Vapor



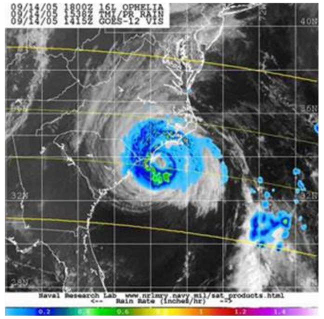

Atmospheric temperature and humidity profiles



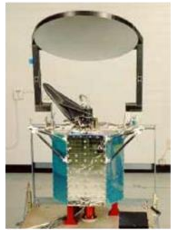
Sea Ice



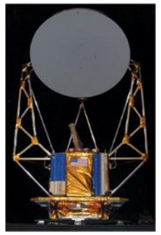
Precipitation



SSM/I F8-F15
1987-



SSMIS F16-F20
2003-



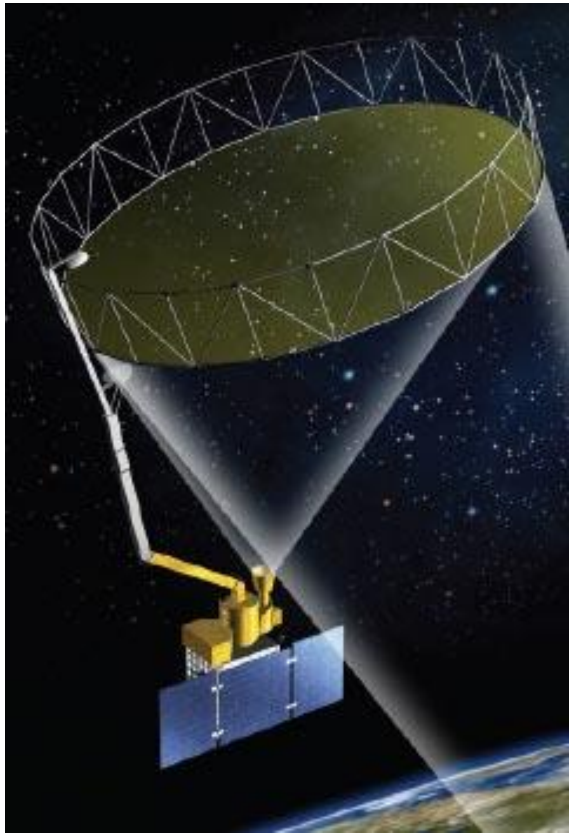
WindSat
2003 -

AMSR-E/AMSR-2
2002 -

GMI - 2014

# ANTENNA NEEDS

- Large aperture to support low-frequencies < 10GHz
  - 2m diameter to replicate program of record
  - 3-6m diameter to make advances
- Broad frequency range up to 200 GHz
  - Though < 1m aperture needed above 90 GHz
- Low mass to minimize spun momentum
  - Typical spin rates of 30 RPM desired
  - Small spacecraft generally prefer momentum < 50Nms
  - Need to also minimize static/dynamic imbalances
- Stow into ESPA grande volume
  - Can use volume in adjacent ports if needed
- Minimize reflector surface loss (emissivity)
- Minimize surface imperfections (e.g. faceting)



# AGENDA FOR WORKSHOP MEETING 1

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| **4.5hours** | **Total Time** | | |

# OVERVIEW OF CURRENT JPL ANTENNA CAPABILITIES

PRESENTER: PAULA BROWN

Jet Propulsion Laboratory
California Institute of Technology

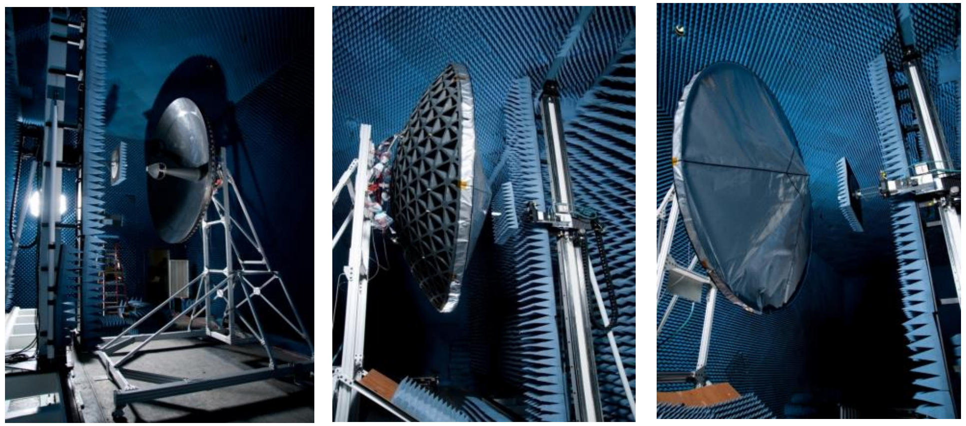
# JPL ANTENNA CORE TECHNOLOGIES

- Reflectors
- Reflectarrays
- Patch Arrays
- Wire Antennas
- Horns and Biconicals
- Slot Arrays
- Lenses
- EM Analysis
- Antenna Test Facilities

# REFLECTOR ANTENNAS

- In-house reflector and feed RF design
- Reflector mechanical design and fabrication generally subcontracted
- Testing generally performed in-house

**Juno Telecom: 2.5m X/Ka High Gain Antenna (HGA)**



Reflector fabricated by ATK (now Northrop Grumman)

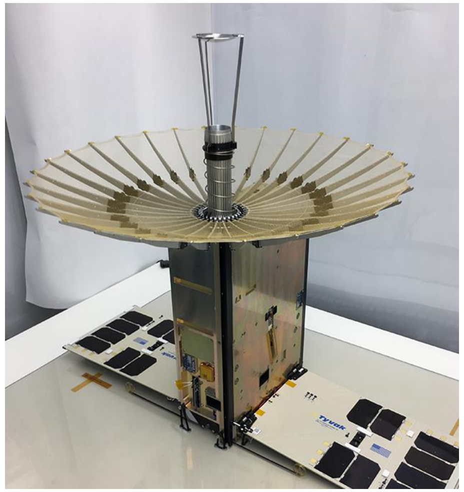
**CloudSat**

- 94 GHz shaped offset antenna for cloud-profiling radar
- 1.85m aperture
- Quasi-optical Transmission Line (QOTL)
- Reflector fabricated by Composite Optics Inc. (COI, now Northrop Grumman)

**SMAP & NISAR Instrument Antennas**

6-m and 12-m Northrop Grumman AstroMesh reflectors

# MORE REFLECTOR ANTENNA EXAMPLES



### RainCube

- 0.5m Ka-band radar antenna
- 1.5U stowage volume
- Designed and built at JPL

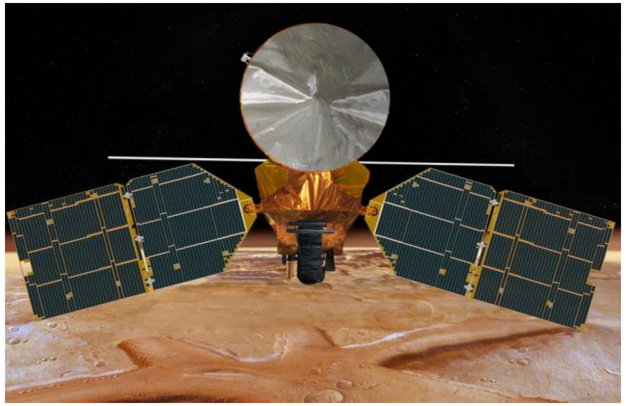
### Aquarius

- 2.5m L-band radar/radiometer antenna
- Solid reflector
- Stowed configuration shown
- Reflector fabricated by Composite Optics Inc. (COI, now Northrop Grumman)

### EOS Microwave Limb Sounder Instrument on Aura

- 0.8m x 1.6m solid reflector
- 118GHz – 640 GHz
- Reflector fabricated by ATK (now Northrop Grumman)

### Mars Reconnaissance Orbiter



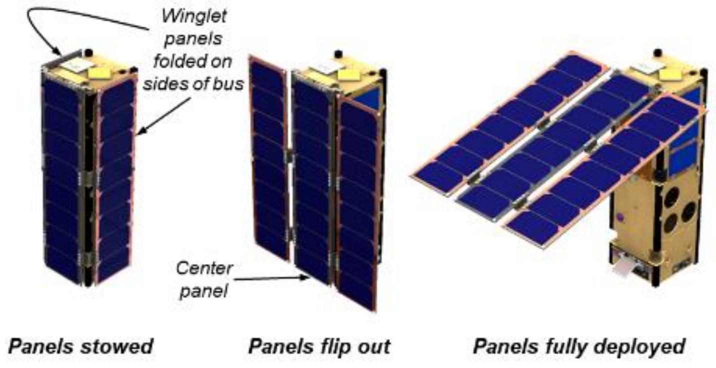
- 3m X/Ka telecom antenna
- Gimbaled solid reflector
- Reflector fabricated by AASC through a Lockheed Martin subcontract

# REFLECTARRAY ANTENNAS

JPL is a leader in reflectarray antennas for spacecraft

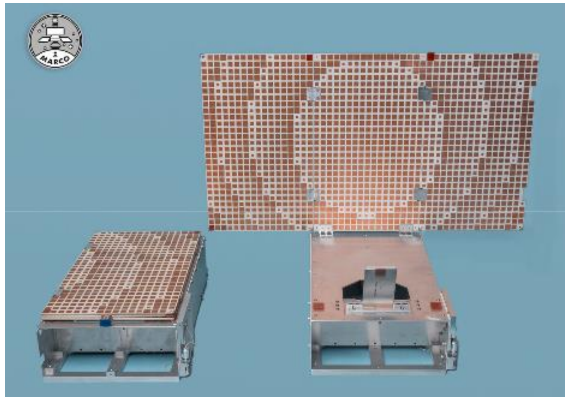
- Reflectarray and feed RF design
- Panel structure design to ensure flatness over temperature

**ISARA**



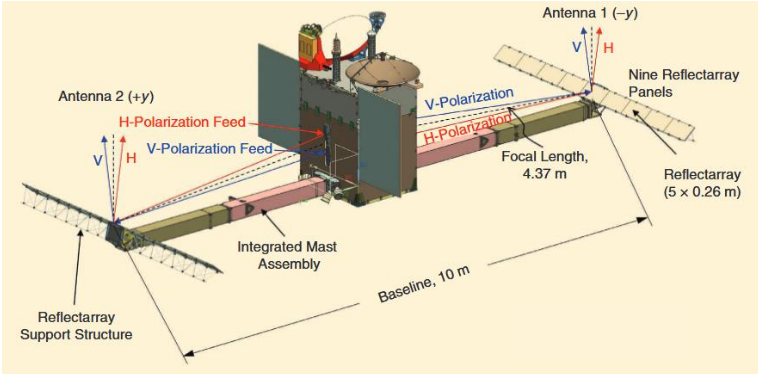

- Ka-band reflectarray integrated with the solar array
- Stowed on 3U cubesat
- Deployed aperture was ~25cm x ~34cm

**MarCO**



- X-band reflectarray
- Stowed on 6U cubesat
- Deployed aperture was ~33.5cm x ~60cm

**SWOT**




- Ka-band reflectarrays for a radar interferometer
- Boom and reflectarrays stow compactly for launch
- Deployed aperture 5m x 0.26m

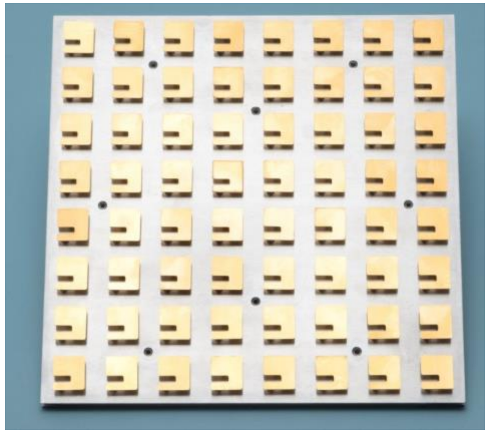
# PATCH ARRAYS

- Arrays from P-band to W-band, both for science instrument and telecom applications
- Passive and active arrays

**JUNO 600 MHz Metal Patch Array for Microwave Radiometer Instrument**

Metal patch array designed to operate in the harsh radiation environment at Jupiter

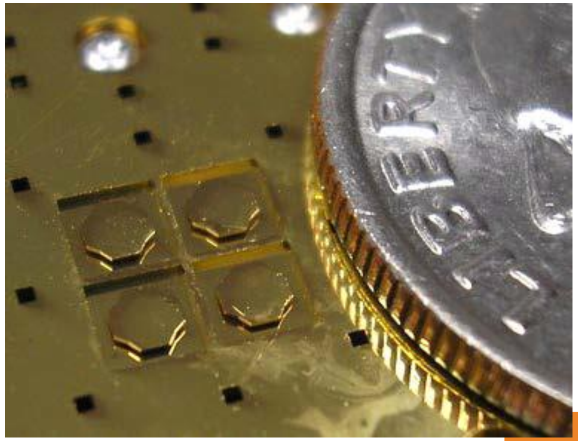
**Europa Lander Patch Array (Technology Development)**



- Covers both X-band Tx and Rx bands
- Circular polarization
- Single tile shown on the left
- Full array comprises 16 tiles

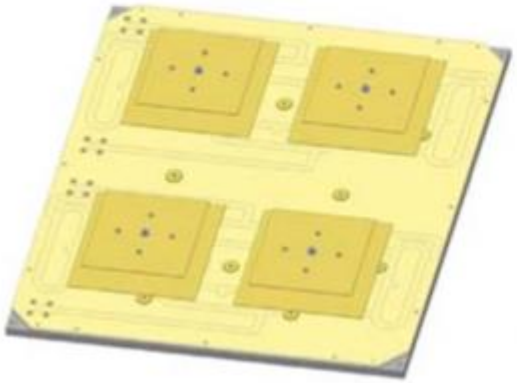
**W-band Metal Patch Array (Technology Development)**

- 94 GHz for potential cloud profiling radars
- Dual linear polarization
- Fabricated by Nuvotronics, LLC



# MORE PATCH ARRAYS

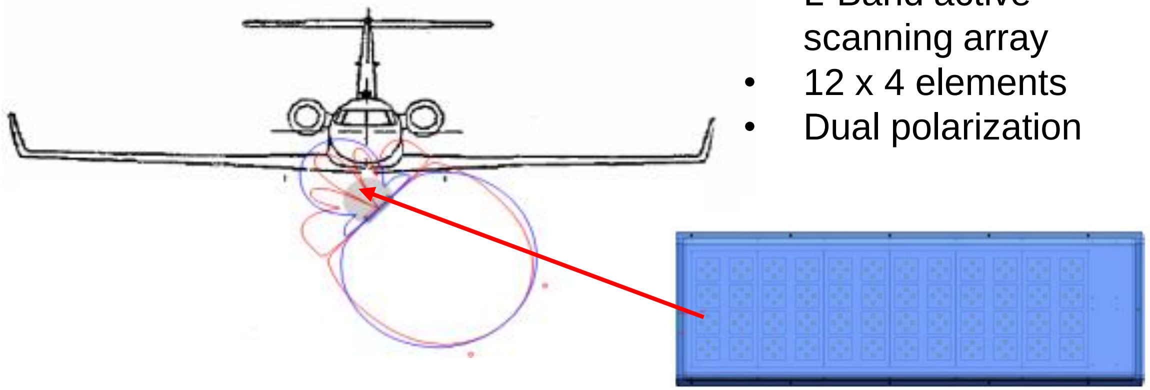
## NISAR L-band Feed Array



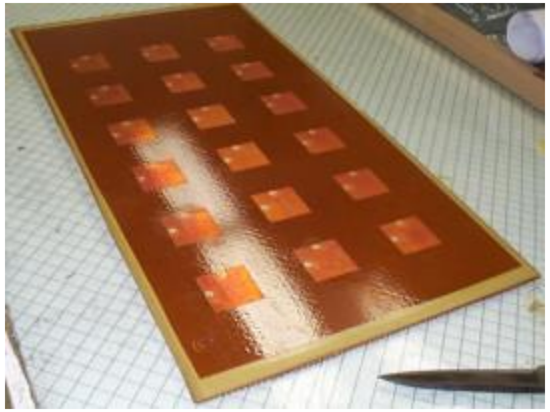
- L-band dual stacked metal patches
- One tile with four elements shown on the left
- Full array is 2 x 12 elements
- Groups of the elements are combined through digital beam-forming, allowing to scan the SAR beam off the 12m Astromesh reflector

## UAVSAR – L-band Configuration

- L-Band active scanning array
- 12 x 4 elements
- Dual polarization



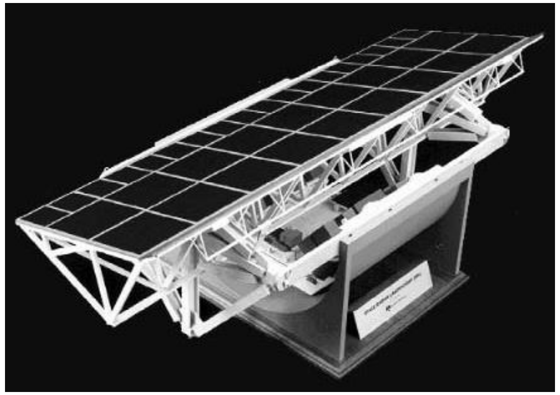
## Deep Impact



S-Band non-scanning phased array for impactor – flyby spacecraft communication link

## SIR-C and SRTM

- **Shuttle Imaging Radar SIR-C**
  - First phased-array SAR antenna in space (1994)
  - Antenna manufactured by Ball Aerospace
  - L-band, C-band, and X-band
- **Shuttle Radar Topograph Mission (SRTM)**
  - First spaceborne implementation of a single pass interferometer (2000)
  - Reused the SIR-C antenna
  - C-band and X-band



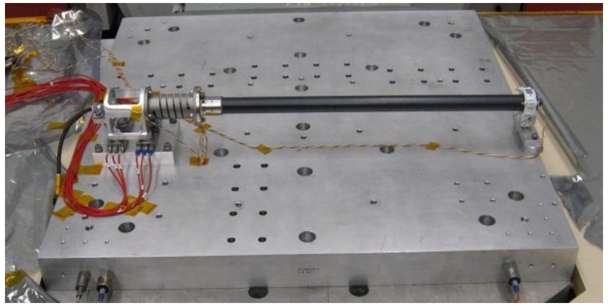
# WIRE ANTENNAS

- JPL frequently designs and builds wire antennas for specific applications
- Frequently, spacecraft accommodations are such that a new antenna design is required
- Most common frequency bands are UHF and X-band

**Mars UHF Helix Antenna**

- Wideband helix design covers transmit and receive bands for Mars proximity link
- Originally designed for the Mars Science Laboratory project, the design has been used for four Mars projects
- Designed and built at JPL

**UHF and X-band Dipoles**



Wire antenna examples
- MER pop-up monopole
- MSL descent stage dipole

**MarCO UHF Pop-up Loop Antenna**

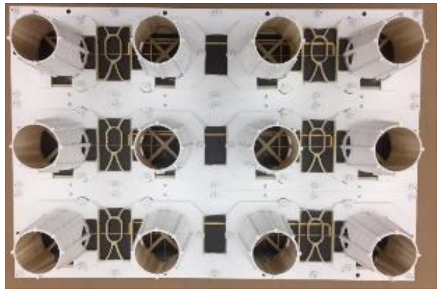
- Compact stowage enabled packaging on the side of the MarCO cubesats
- Circular polarization

# MORE WIRE ANTENNAS

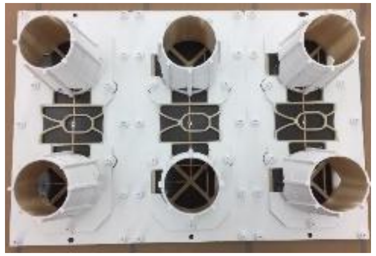
## Sentinel 6 Helix Array

L-Band digital beamformed phased array.
Helix array on 3D printed on Ultem cones.

GNSS-RO-AFT PRIOR TO PAINTING



GNSS-RO-AFT



GNSS-RO-FORE

## Europa Clipper REASON HF and VHF Dipoles

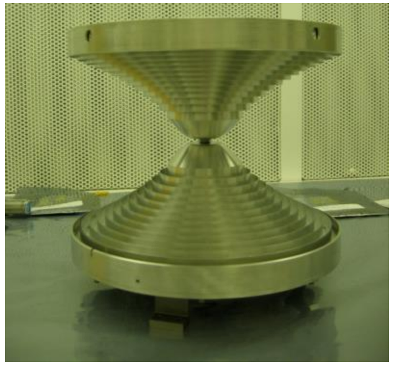
- 9 MHz and 60 MHz dipole arrays
- STACER dipoles built by Heliospace, Inc.

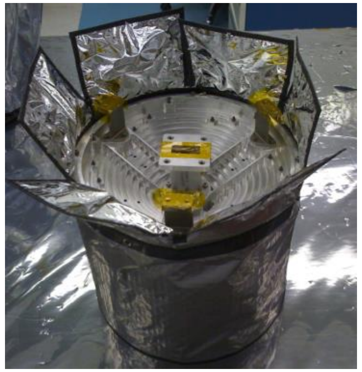
Below: HF Antenna Testing on JPL's West Range

# HORNS AND BICONICALS

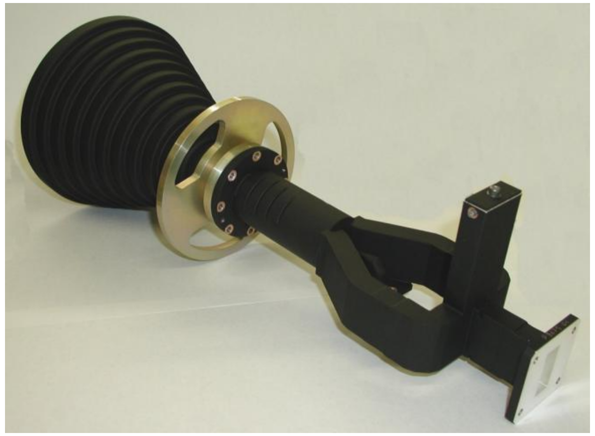
- JPL designs many types of waveguide style antennas
- Some units are fabricated in-house, some fabrications are subcontracted out, depending on the fabrication methods
- A few examples are shown

**JUNO X-band Biconical Antenna with Meanderline Polarizer and Thermal Cover**



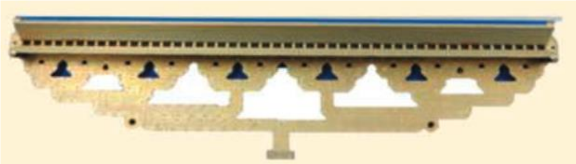


**MRO Feed for Telecom High Gain Antenna**



- X/Ka dual frequency feed
- Designed by JPL
- Fabricated by Custom Microwave, Inc.

**SWOT Feeds for Radar Reflectarray Antennas**



- Ka-band array horns
- The two provide two orthogonal polarizations to feed the reflectarrray
- 20:1 aspect ratio beam
- Designed by JPL
- Fabricated by Rantec

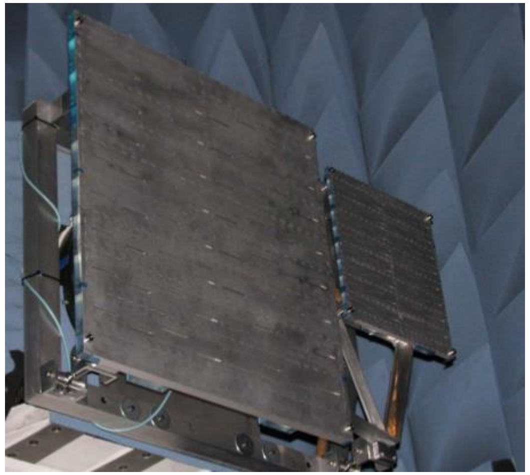
# SLOT ARRAYS, LENSES

## Slot Arrays

- Design performed in house
- Fabrication subcontracted out

### Juno Microwave Radiometer Antennas

- Three antennas: 2.6 GHz, 5.2 GHz, and 10 GHz
- Tapered aperture distribution for low sidelobe performance
- Fabricated by Rantec

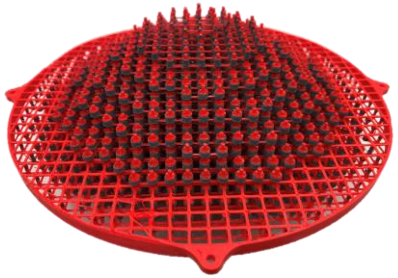


**Left:** 2.6 GHz and 5.2 GHz Juno slot arrays

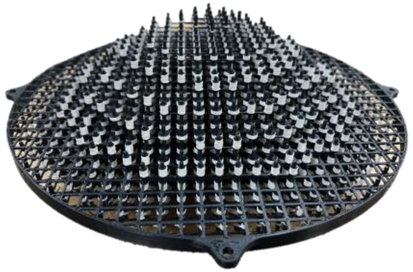
## 3D Printed Lenses

- Technology development effort with UCLA
- Artificial dielectric (AD) lenses
- Potential advantages
    - Wide bandwidth
    - Wide beam scan
    - Low sensitivity to tolerances
    - No blockage

**Gradient Density Lens**



**Aluminum AD Lens**

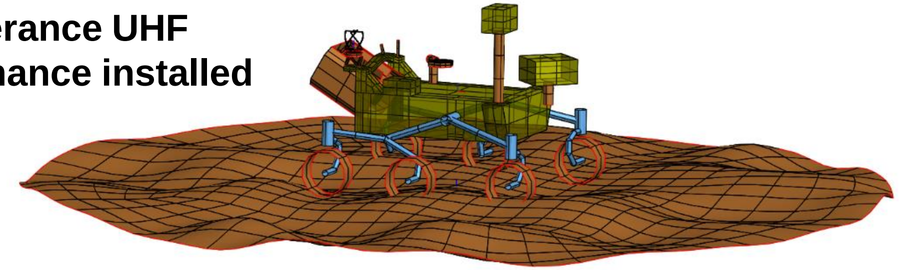


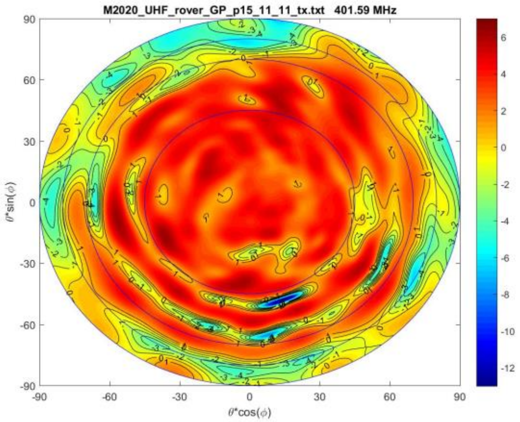
**$TiO_2$ AD Lens #1**

# EM ANALYSIS

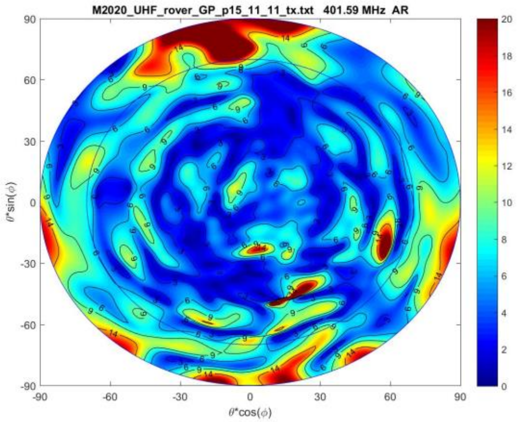
- Knowledge of the installed antenna performance can be critical for spacecraft missions
- JPL performs detailed modeling for both telecom and instrument antennas

**M2020: Perseverance UHF antenna performance installed on the rover**



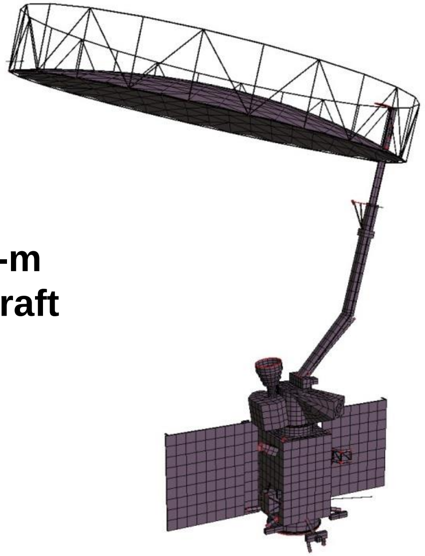


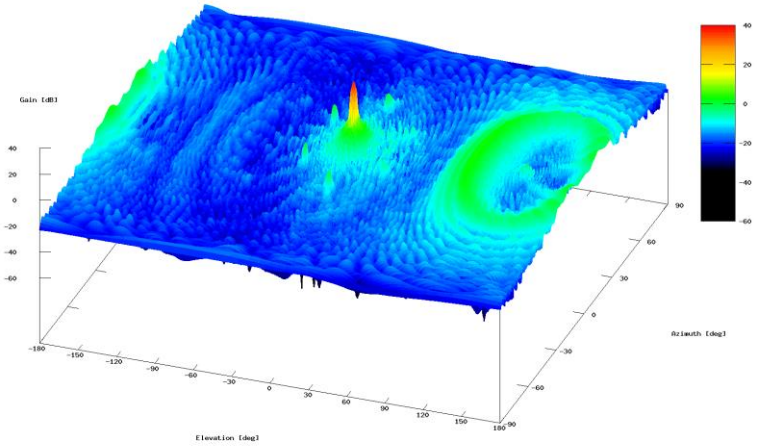

**Co-Pol**




**Axial Ratio**

**SMAP: Performance modeling of 6-m Instrument Antenna with the Spacecraft**

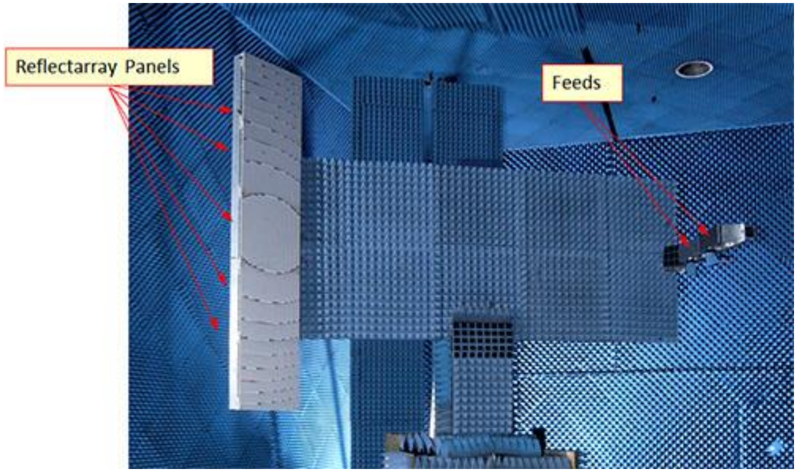




# ANTENNA TEST FACILITIES

- The JPL Mesa Antenna Measurement Facility includes:
  - Planar and cylindrical near-field ranges
  - Outdoor ranges from UHF to 94 GHz
  - Multipaction and ionization test capabilities

**Near-Field Ranges**




- 13' x 30' planar scanner
- Spherical range
- Cylindrical range

- *Shown: WSOA reflectarray antenna on the cylindrical range*

**Far-field Ranges**

- Several outdoor ranges, including 1200' and 3000' ranges
- Shorter indoor ranges in anechoic chambers

- *Shown: Mars Science Laboratory cruise stage mock-up on the 3000' range tower*

**High Power Test Facilities**

- Several vacuum chambers for high power testing
- One chamber is a large bell jar in an absorber-lined screen room, which enables high power testing of radiating antennas

- *Shown: The Aquarius L-band feed assembly in the large bell jar*

# SUMMARY

- JPL has many years of experience in designing and implementing a wide variety of antennas for large spacecraft
- JPL historically has worked with subcontractors on many of its antenna developments
- Mission concepts are moving towards smaller spacecraft
- JPL has developed a limited set of solutions for SmallSats and CubeSats, but there are large gaps between the current solution set and the mission concept needs

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# CURRENT TECHNOLOGY GAPS FOR MISSION NEEDS

PRESENTER: JONATHAN SAUDER

Jet Propulsion Laboratory
California Institute of Technology

# FUTURE NASA / JPL INSTRUMENTS:
## DEPLOYABLE ANTENNA TECHNOLOGY GAPS

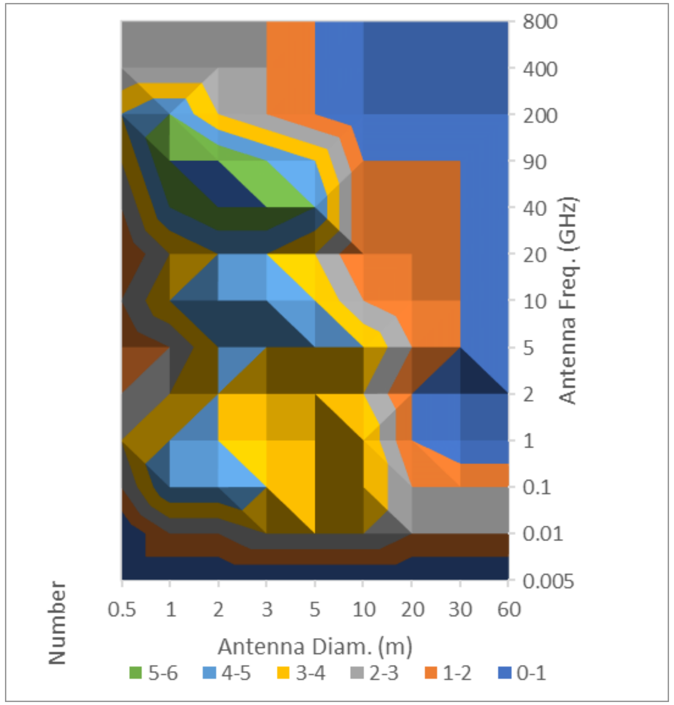
| Science Program | Code | Antenna Technology | |
|---|---|---|---|
| | | Size | Freq |
| Planetary Boundary Layer | PBL | 2.0 m | 167-175 GHz |
| Cloud Profiling Radar | Cloud Cube | 0.5-0.75 m<br>2.0 m | 94<br>94 or 240 GHz |
| Pressure Radar | Pressure Radar | 0.5-0.75 m | 65-70 GHz |
| Large Aperture Rotating Reflectors | Radiometer | 2-6 m<br>2m | 6-90 GHz<br>90-900 GHz |
| Surface Mobile Platform | – | < 20 x 20 x 20 $cm^3$ | 700-800 MHz |
| Surface Deformation and Change | SDC | 10.5 x 2.3 $m^2$ (min)<br>7.9 x 1.7 $m^2$ (min)<br>7.0 x 1.5 $m^2$ | L-band or<br>S-band or<br>C-band |
| Surface Topography and 3D Vegetation Structure | STV | 0.8m x 7m | L-band or S-band |
| Earth Ice Sheets and Aquifers | ISA | < 4m ($\leq \lambda/2$) | 45 MHz |
| Small Body Characterization | SBC | < 3-60m ($\leq \lambda/2$) | 5-100 MHz |

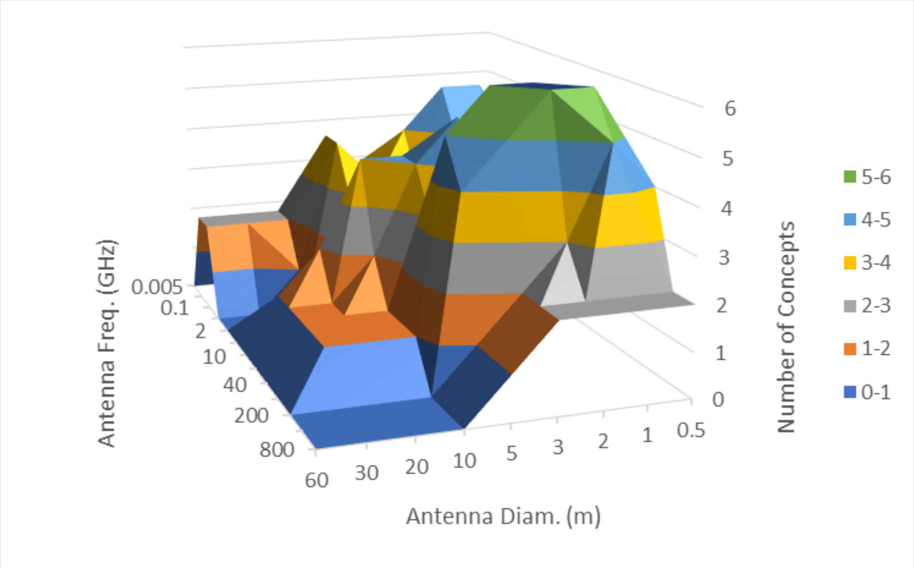
# CONCEPT INPUTS: JPL POTENTIAL MISSIONS

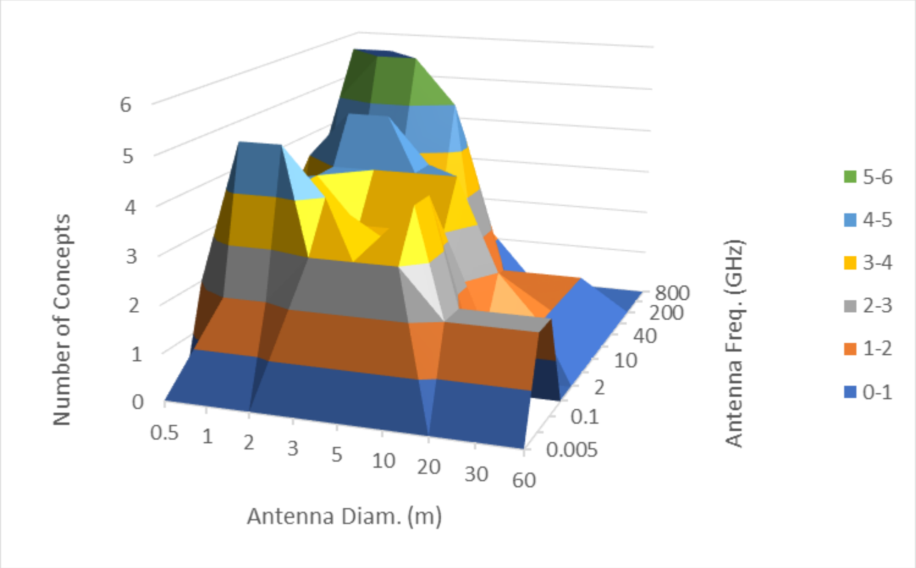
| Name | Near vs Long | Science Return | Estimated Ant. TRL | Satellite Size | # Satellites Required | Minimum Frequency | Maximum Frequency | Minimum Aperture Size | Maximum Aperture Size | Movement Required | Mission Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ES Radar 1 | Near (<5yr) | Major | TRL2 | 12U | 1 | 35 GHz | 238 GHz | 1.6 m | 2.1 m | No Movement | W-band radar targets 94.05 GHz |
| ES Radar 2 | Long (>5yr) | Breakthrough | TRL2-3 | ESPA | 1 | 155 GHz | 175 GHz | 0.5 m | 2 m | None | PBL mission |
| ES Radar 3 | Near | Major | TRL2-3 | ESPA | 1 | 167 GHz | 175 GHz | 0.5 m | 1 m | 1.5 degree scanning | |
| ES Radar/Radiometer 1 | Near | Major | TRL2-3 | 6U | 1 | 35.75 GHz | 239 GHz | 0.5 m | 1 m | None | 35.75 GHz is the near term focus |
| ES Radiometer 2 | Long | Sustained | TRL2-3 | ESPA | 1 | 6 GHz | 200 GHz | 1m | 4m | Conical | Reflector required to spin at rate close to 30RPM |
| ES Radar 4 | Near | | TRL2-3 | 1 m^2 | 1 | 13.4 GHz | 94 GHz | 1m x 60cm | 5m x 3m | None | Parabolic-cylindric reflector |
| ES Radar 5 | Near | | TRL6 | ESPA | 2-4 | 36 GHz | 36 GHz | 1.6 m | 3m | None | |
| ES Radar (SAR) 6 | Long | Sustained | TRL3-4 | ESPA to Flagship | 1-9 | 1.2 GHz | 3.4 GHz | 5 m^2 * | 24 m^2 * | None required (spacecraft rotates) | Electronic steering in the elevation direction would be beneficial (3 or 4 steps spanning ~20 deg) |
| ES Radiometer 3 | Long | Major | TRL2-3 | ESPA | >= 1 | 10 GHz | 890 GHz | 0.3 m | 4m | Conical | |
| ES Radar Sounder 1 | Near | | TRL3-5 | | | 240 MHz | UHF | 10m | 10m | None | |
| ES Mission 1 | Long | Breakthrough | TRL3-5 | ESPA | 6-12 | 1 GHz | 10 GHz | 0.8 m | 7m | None | |
| ES Radar 7 | Near | Major | TRL3 | Larger | | 36 GHz | 36GHz | 5x0.3m | 5x0.3m | Conical | |
| ES Sounder 2 | Near | Major | TRL2-3 | 6U/ESPA | 1 | 360 GHz | 640 GHz | 70cm X 30cm | 4m x 50cm | 1 degree scanning | |
| ES Radar Sounder 3 | Long | Major | TRL3-5? | 6U/ESPA | 1-20 | 40 | 50 MHz | 3 | 12 m | None | |
| PL Radar 8 | Near | Breakthough | | 6U/ESPA | >=2 | 5 MHz | 100 MHz | 1.5 m | 30 m | None | Dipoles likely, depolyed once. In-family with sounders (MARSIS, SHARAD, REASON). |
| ES Radar 9 | Long | Major | TRL2-3 | 6U | | 65 GHz | 70 GHz | 0.5 m | 1m | None | |
| PL Surface Radar 10 | Near | Major | TRL3-5 | Rover | 1 | 120 MHz | 2 GHz | 20 cm | <1 m | None | Rover-mounted GPR antenna. |
| PL Radar 11 | Long | Major | TRL3-5 | 6U/ESPA | 1 | 300 MHz | 1.1 GHz | 58.8 cm (height) | 92.2 cm (height) | None | Mapping of shallow regolith in permanently shaded regions |
| PL Surface Radar 12 | Near | Major | TRL3-5 | Helicopter | | 0.3 GHz | 2 GHz | 1m | 2.5m | None | The antenna needs to be extremely light (<1 Kg max) |
| PL Radar 13 | Long | Major | TRL2-3 | ESPA | 1 | 35.75 GHz | 94.05 GHz | 2 m | 4 m | None | |
| PL Radiometer | Long | Major | TRL3-5 | 1m class | 1 | 0.3 GHz | 6 GHz | 2m | 10m | Desired | |
| PL Surface Radar 12 | Long | Major | TRL3-5 | Rover(s) | na | 100s of kHz | 120 MHz | 1 m | 600 m | Yes | unspooled rover tether |
| PL Surface Radar 12 | Long | Major | TRL3-5 | PL Surface | na | 100s of kHz | 100s of MHz | 1 m | 600 m | No | coupled smaller antennas with multistatic capabilities |

ES = Earth Science PL = Planetary PL Surface = Non-orbiting platform

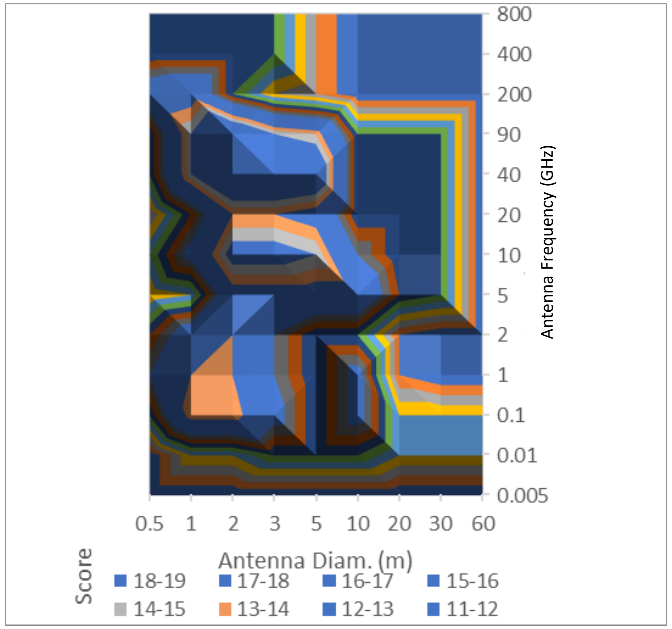
# QUANTITY OF TARGETS: BINNING NUMBER OF MISSION CONCEPTS BY FREQUENCY AND ANTENNA DIAMETER

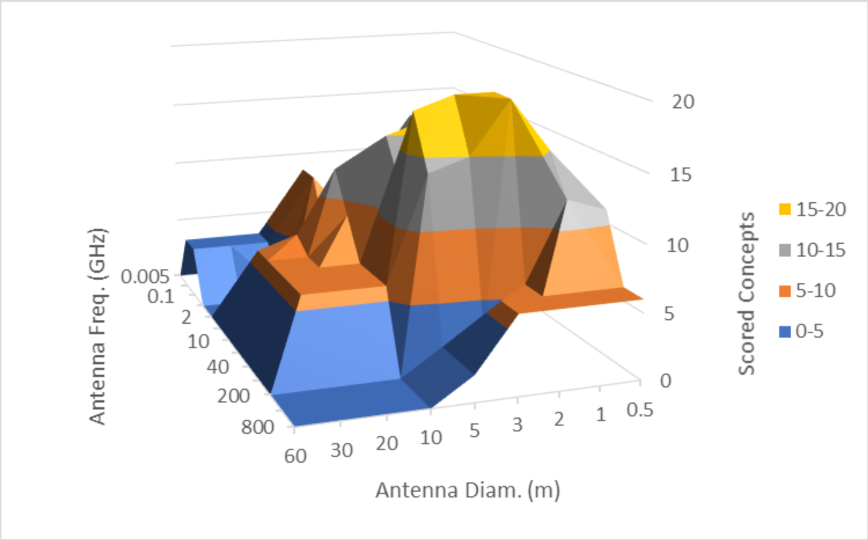


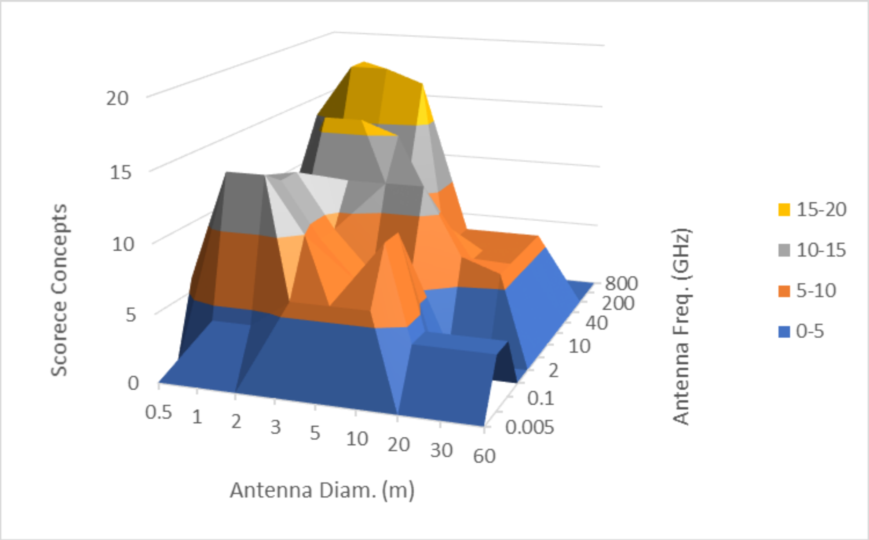



# IMPORTANCE OF TARGETS: SUMMING MISSION CONCEPT SCORES BY FREQUENCY AND ANTENNA DIAMETER



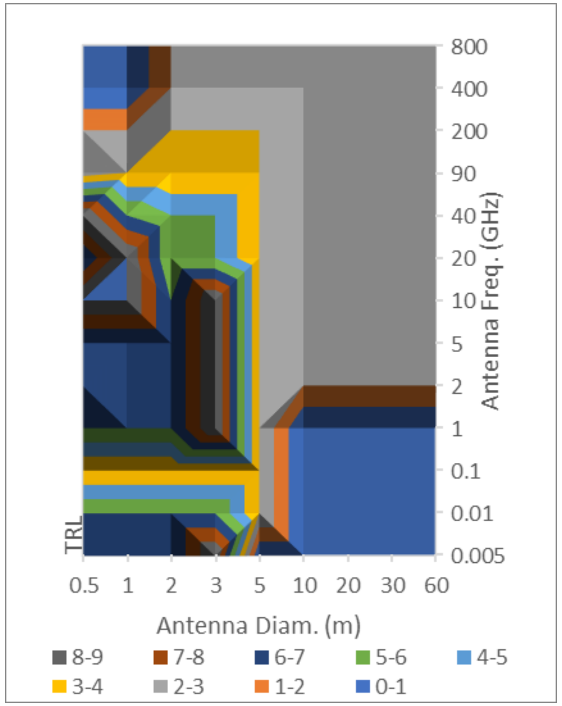



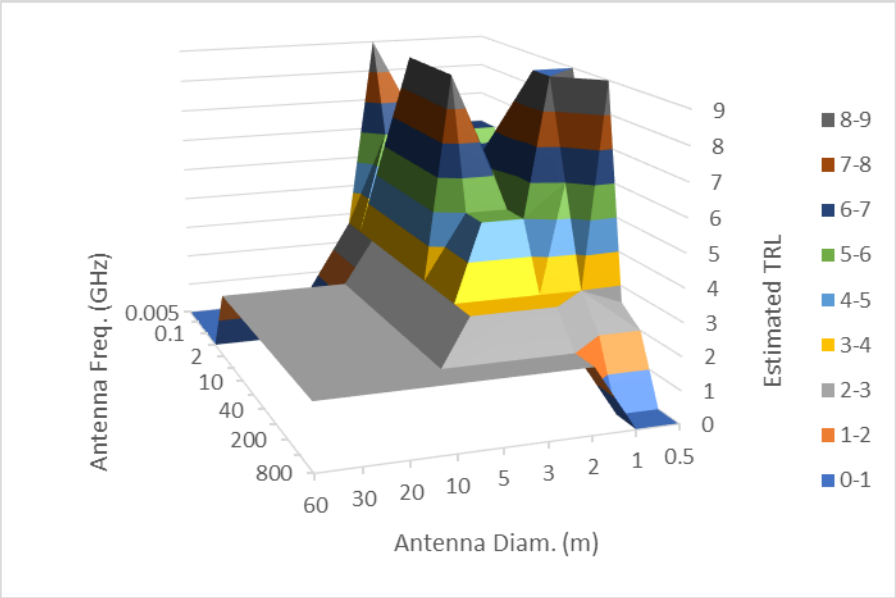



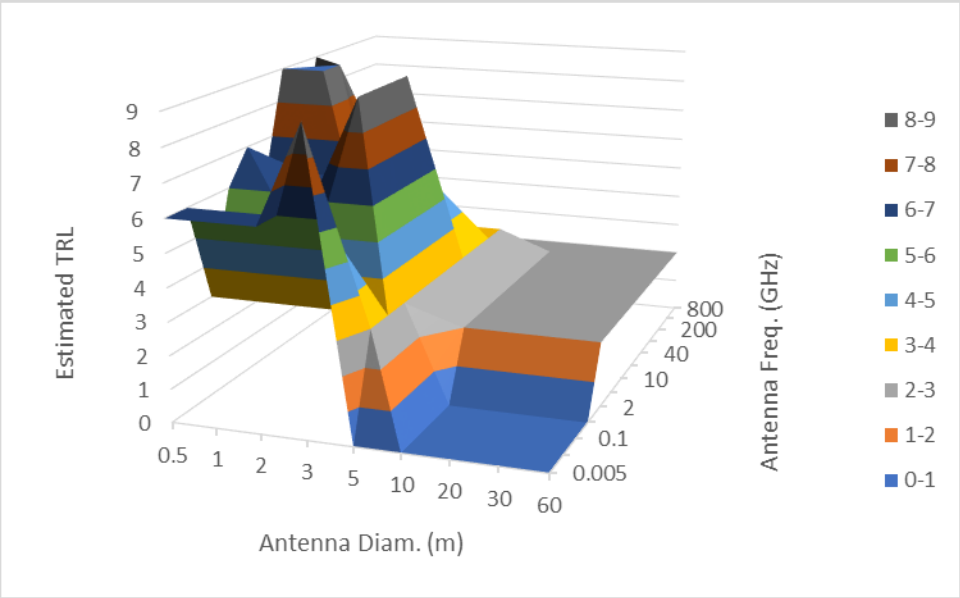

Scored Concepts

- Sustained = 1 point
- Major = 2 points
- Breakthrough = 3 points
- Near is a 2x multiplier.

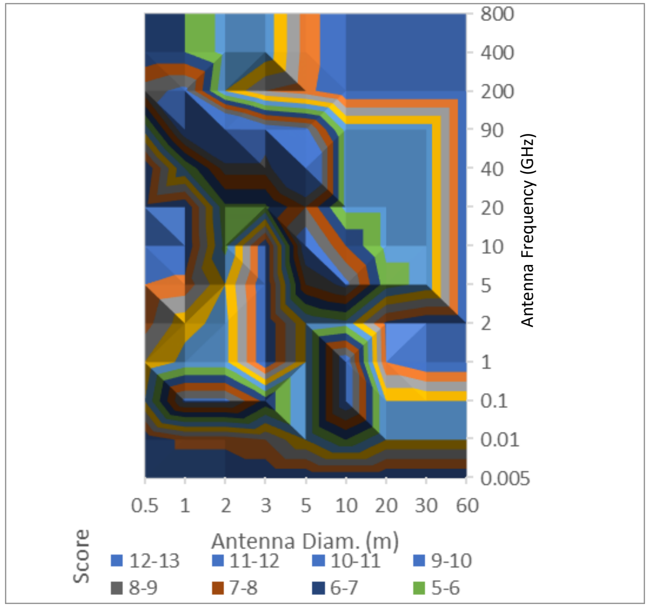
# STATE OF THE ART: ESTIMATED TRLS OF EXISTING ANTENNA TECHNOLOGIES

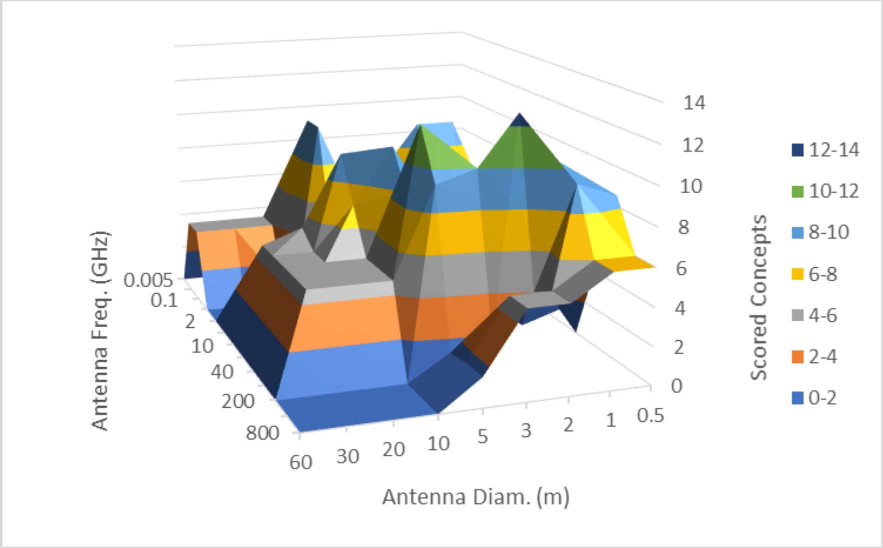


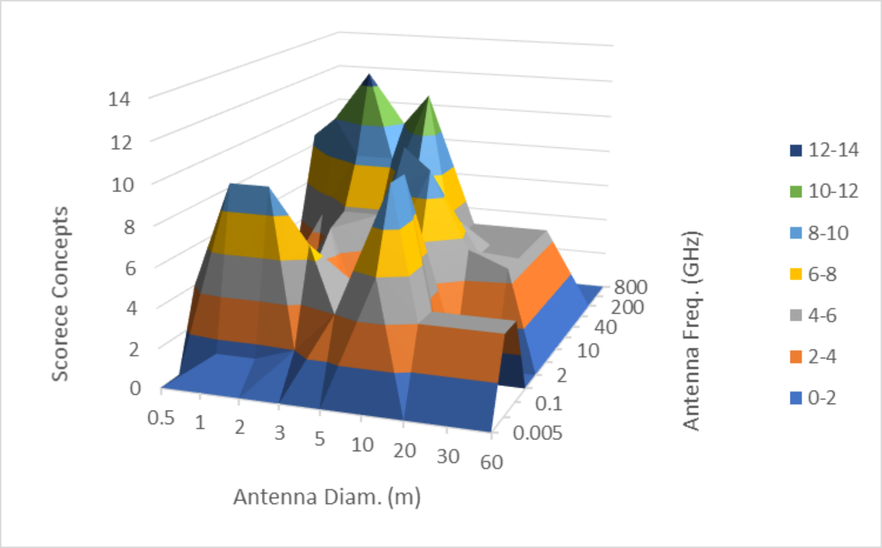



# DEMAND OF EACH REGION



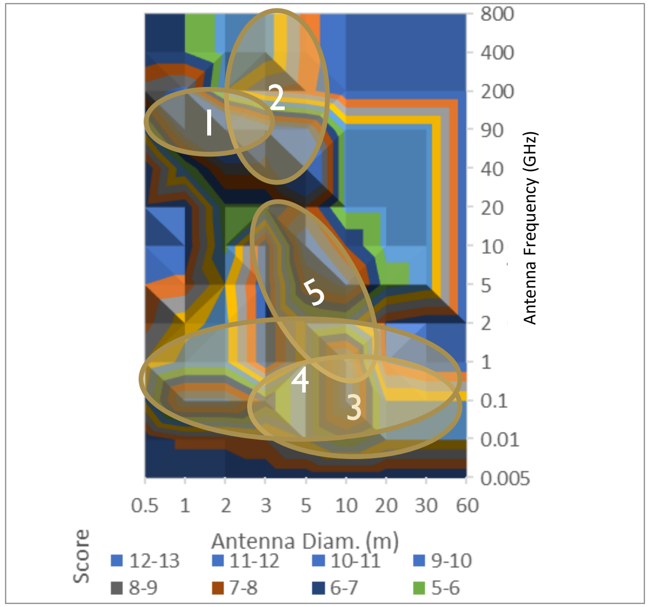



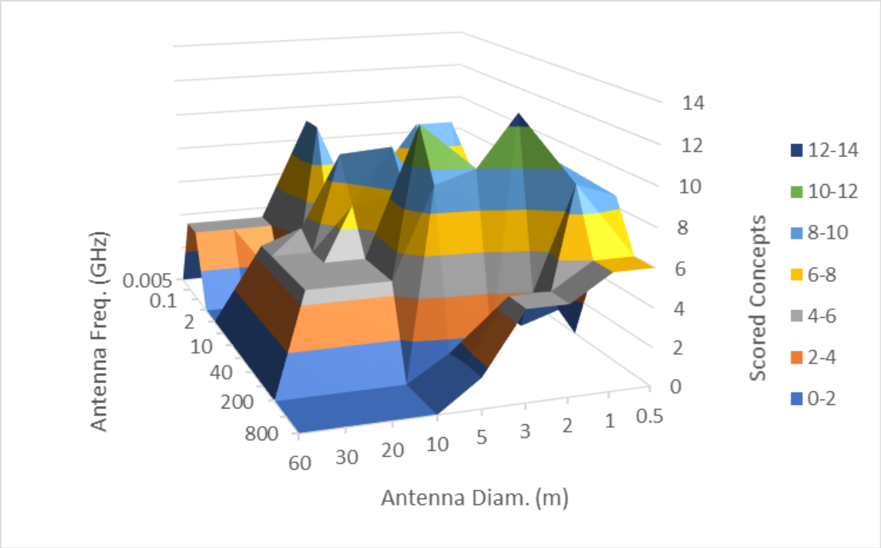

Score = Concept Score*(9-Esitmated TRL)/9

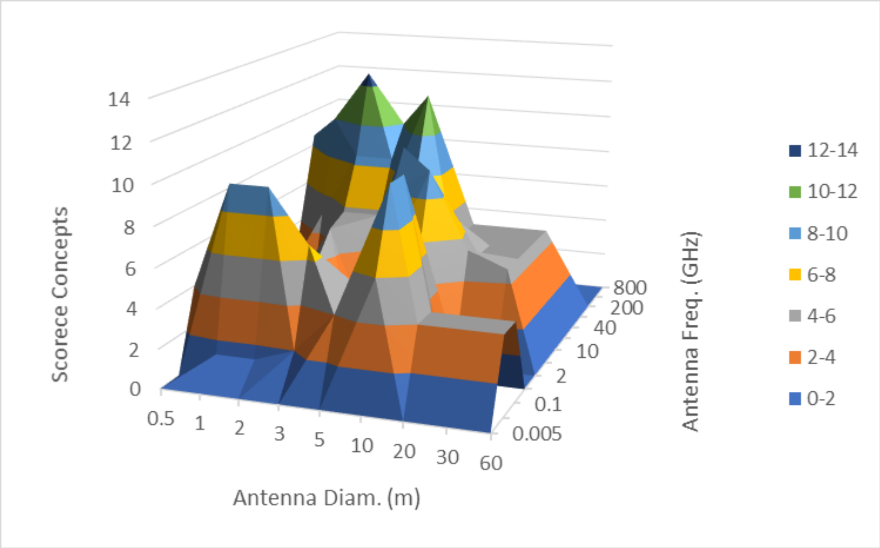
# SUMMARY OF CURRENT GAPS

1. Reflectors suited for mm/sub-mm (70GHz and higher), includes lower frequencies as well
2. Ultra-low-mass, 2-6m large aperture rotating 60-90 GHz reflectors and Ultra-low-mass, 2-6m large aperture rotating 90 GHz+ reflectors
3. Large broadband antennas for low-frequencies (0.01-1 GHz) monolithic
4. Surface Mobile Platform Antennas
5. 500MHz to 30 GHz (P through Ku band) Long, Narrow Apertures

# ANTENNA DEMAND: COMBINING MISSION CONCEPT SCORES WITH ESTIMATED ANTENNA TRL




= Gap

Score = Concept Score*(9-Esitmated TRL)/9

# AGENDA FOR WORKSHOP MEETING 1

| Time | Person | Description | Start Time |
|---|---|---|---|
| 15min | Sauder | Overview/Agenda | 8:30 AM |
| 45min | Haynes/ Cooper/Rodriguez Monje/ Beauchamp/ Brown | Instrument Aspirations | 8:45 AM |
| 15min | P. Brown | Overview of Current JPL Antenna Capabilities | 9:30 AM |
| 20min | Sauder | Current Technology Gaps for Mission Needs | 9:45 AM |
| 20min | Hodges | Derived Antenna Requirements | 10:05 AM |
| 30min | Group | Technical Question and Answer | 10:25 AM |
| 10min | | BREAK | 10:55 AM |
| 20min | Hyon | Funding Mechanisms and the Make vs Buy Decisions at JPL | 11:05 AM |
| 20min | Broderick | Technology transfer opportunities with JPL | 11:25 AM |
| 30min | Lewis | How to propose SBIR's for solutions to the gaps | 11:45 AM |
| 5min | Sauder/Hodges | Who to talk to at JPL. Finding the right SME | 12:15 PM |
| 10min | Sauder | Next Steps for Continuing the Conversation with JPL | 12:20 PM |
| 30min | Group | Programmatic Question and Answer | 12:30 PM |
| **4.5hours** | **Total Time** | | |

# DERIVED ANTENNA NOTIONAL REQUIREMENTS

RICHARD HODGES

Jet Propulsion Laboratory
California Institute of Technology

# 1) REFLECTORS SUITED FOR MM/SUB-MM (70GHZ AND HIGHER)

## PBL & CLOUD RADAR ANTENNA TECHNOLOGIES

| | | |
|---|---|---|
| ***Primary Need*** | ***Large aperture > 90 GHz deployable antenna for ESPA-class missions*** | |
| **Key challenges** | • **90+ GHz deployable reflector with high-accuracy, low-loss surface**<br>▪ Efficiency (surface tolerances, surface roughness loss, etc.)<br>▪ Stowage volume and cost<br>• **Beam pointing (control, knowledge, electronic steering)** | |
| **Key and driving requirements** | ***Passive Antenna***<br>• Frequency range<br>• Aperture diameter<br>• Thermal-deformation requirements<br>• RMS surface accuracy<br>• Mass<br>• Configuration | • 94-240 GHz (specific project interest in 70 GHz)<br>• 2m (0.5m min)<br>• LEO Orbit<br>• < $\lambda$/20 min, < $\lambda$/40 preferred<br>• 15-20 kg/m$^2$ areal mass density<br>• Offset parabolic or center-fed Cassegrain |
| | ***Electronic Scanning Antenna***<br>• Scan capability<br>• Pointing accuracy | • Scan ±30 beamwidths in < 0.1 s<br>• < Beamwidth/4 |
| **State-of-the-Art** | • Microwave Limb Sounder, 1.6m x 0.8m. 118, 190, 240, and 640 GHz.<br>• CloudSat Radar 1.8m reflector at 94 GHz, with QOTL feed | |

***Key Technologies***

- Deployable >94 GHz reflector
- Beam scanning capability

***EOS MLS Antenna***

# 1) REFLECTORS SUITED FOR MM/SUB-MM (70GHZ AND HIGHER), INCLUDES LOWER FREQUENCIES AS WELL

| Parameter | Type | CloudCube | CloudCube | PBL Radar | Pressure Radar | Pressure Radar |
|---|---|---|---|---|---|---|
| **Frequency** | Notional RF Requirements | 94 GHz | 94 GHz, 240 GHz | 167 – 175 GHz | 65 – 70 GHz | 65 – 70 GHz |
| **Bandwidth** | | | | | 5 GHz | 5 GHz |
| **Gain** | | | 63 dBi, 70 dBi | | | 45dB gain |
| **Type of coverage** | | | Pencil beam | Pencil beam | | Pencil beam |
| **Losses (emissivity)** | | < 5% (reflector only) | < 5% (reflector only) | < 5% (reflector only) | < 5% (reflector only) | < 5% (reflector only) |
| **Beamwidth/Side lobes** | | | | | | < 1 degree, 20dB SLL |
| **Co-alignment of beams** | Notional Mechanical Requirements | | 0.1 beamwidth | | | |
| **Deployed size range** | | 0.5m to 0.75 m | 2m | 2m | 0.5m to 0.75 m | 2m |
| **Maximum Stowed volume** | | 3U (.36x.12x.12m) | 0.25x0.25x1.0m | 0.25x0.25x1.0m | 1.5 to 2U | 0.25x0.25x1.0m |
| **Maximum Mass** | | 5kg | 60kg (20kg/m^2)<br>*6-12kg (2-4 kg/m^2)* | 60kg (20kg/m^2)<br>*6-12kg (2-4 kg/m^2)* | 3 kg | 60kg (20kg/m^2)<br>*6-12kg (2-4 kg/m^2)* |
| **Surface accuracy/RMS** | | 0.08mm ($\lambda$/40) | 0.03mm ($\lambda$/40) | 0.04mm ($\lambda$/40) | 0.11mm ($\lambda$/40) | 0.11mm ($\lambda$/40) |
| **Scanning/Motion?** | | No | No | ±1.5° cross-track scanning | No | Scanning 45° |
| **Point and stare** | | No | No | No | No | Yes |
| **Location of Use** | | LEO, Tech Demo | Low Earth Orbit | Low Earth Orbit | LEO, Tech Demo | Low Earth Orbit |

# 2) ULTRA-LOW-MASS, 2-6M APERTURE ROTATING REFLECTORS (BOTH 60-90 GHZ, AND >90 GHZ)

| | | |
|---|---|---|
| ***Primary Need*** | ***Large rotating antennas for ESPA-class radiometer instruments*** | |
| **Key challenges** | • **60+ GHz deployable reflector with high-accuracy, low-loss surface**<br>▪ Efficiency (surface tolerances, surface roughness loss, etc.)<br>▪ Stowage volume and cost<br>• **Spinning (rotating) reflector**<br>• **Beam pointing (control, knowledge, electronic steering)** | |
| **Key and driving requirements** | ***Passive Antenna***<br>• Frequency range<br>• Aperture diameter<br>• RMS surface accuracy<br>• Rotation speed<br>• Mass<br>• Configuration | • > 60 GHz<br>• > 2m<br>• < $\lambda$/30 min, < $\lambda$/40 preferred<br>• ~30 RPM<br>• < 4 kg/m$^2$ areal mass density<br>• Offset parabolic or center-fed Cassegrain |
| **State-of-the-Art** | • COWVR, 75 cm aperture, 18-30 GHz | |

***Key Technologies***

- Deployable >94 GHz reflector
- Conical Beam Scanning

***COWVR Antenna***

*75 cm aperture, 18-30 GHz*

# 2) ULTRA-LOW-MASS, 2-6M LARGE APERTURE ROTATING REFLECTORS (BOTH 60-90 GHZ, AND 90 GHZ+)

| Requirements | Type | 6-90 GHz | 90 to 900 GHz |
|---|---|---|---|
| Frequency | Notional RF Requirements | 6-90 GHz | 90 to 900 GHz |
| Bandwidth | | Full band desired | Full band desired |
| Losses (emissivity) | | ~ < 1% | ~ < 1% |
| Beamwidth/Side lobes | | < 1° | < 1° |
| Polarization | | Dual-linear or LCP/RCP | Dual-linear or LCP/RCP |
| Pointing | Notional Mechanical Requirements | Control: 1° typical<br>Knowledge: <10% of beamwidth | Control: 1° typical<br>Knowledge: <10% of beamwidth |
| Co-alignment of beams | | Co-alignment required (either at antenna level or after re-sampling) | Co-alignment required (either at antenna level or after re-sampling) |
| Deployed size range | | 2-6 m | 2 m |
| Stowed volume | | ~50x50x10cm | ~50x50x10cm |
| Mass | | < 10kg (<4 kg/m^2) | < 10kg (<4 kg/m^2) |
| Moment of Inertia | | < 15 kg-m$^2$ | < 15 kg-m$^2$ |
| Surface accuracy/RMS | | 0.11mm ($\lambda$/30) | 0.11mm ($\lambda$/30) |
| Scanning/Motion? | | Conical | Conical |
| Point and stare | | N/A | N/A |
| Location of Use | | Low Earth Orbit: Deployed on boom, f/D of 0.5-1 typical | Low Earth Orbit: Deployed on boom, f/D of 0.5-1 typical |

# 3) LARGE BROADBAND ANTENNAS FOR LOW FREQUENCIES (5-100 MHZ)

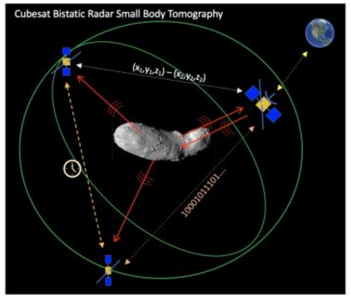
## EARTH ICE SHEETS AND AQUIFERS / SMALL BODY TOMOGRAPHY

| | | |
|---|---|---|
| ***Primary Need*** | ***Kilometer-scale remote sensing radar & small body radar tomography*** | |
| **Key challenges** | • **Distributed aperture / formation flying radar**<br>• **Cost per satellite**<br>• **Compact HF/VHF/UHF deployable antennas**<br>• **High efficiency electrically small antenna**<br>• **Spacecraft dynamics (Moment of Inertia)** | |
| **Key and driving requirements** | ***Distributed Array Architecture***<br>• Center Frequency<br>• Fractional Bandwidth<br>• Polarization | • 5-100 MHz<br>• 20-30%<br>• Dual linear |
| | ***Low Gain Antenna Element***<br>• Antenna gain<br>• Pattern coverage<br>• Mass<br>• Stowage | • 0 dBi minimum. 4-5 dBi preferred.<br>• Omni pattern (dipole) acceptable. Forward hemisphere preferable.<br>• < 2 kg per antenna<br>• 1-2 U |
| **State-of-the-Art** | • REASON, Rosetta-CONSERT, DHFR | |

### *Key Technologies*

- Distributed aperture radar
- Bistatic Radar
- Compact HF/VHF/UHF deployable antennas

**Distributed Array Radar**




**Bistatic Small Body Radar**

# 3) LARGE BROADBAND ANTENNAS FOR LOW-FREQUENCIES (5-100 MHZ)

## EARTH ICE SHEETS AND AQUIFERS / SMALL BODY TOMOGRAPHY

| Requirements | Type | Earth Ice Sheets | Small Bodies |
|---|---|---|---|
| Frequency | Notional RF Requirements | 45 MHz (center) | 5-100 MHz (center) |
| Bandwidth | | 10 MHz (return loss >10 dB) | 20-30% fractional BW |
| Gain | | > 0 dB (desire > 4 dB) | > 1.6dB |
| Losses (emissivity) | | N/A | 0.8% efficient |
| Backlobes | | Minimize solar panel interaction | Minimize |
| Polarization | | Dual-pol | Dual-pol |
| Pointing | Notional Mechanical Requirements | 1 deg control or less, 0.1 deg knowledge or less (orbital positioning driven by GPS) | Design control of peak gain < 5 deg. Characterization < 1 deg. Other pointing control/knowledge will come from S/C |
| Deployed size range | | > 4m ($\geq\lambda/2$) | 3-60m ($\lambda/2$) |
| Stowed volume | | 1/2U Ideal, 1-2U Competitive. Folded geometry possible. | 1/2U Ideal, 1-2U Competitive |
| Mass | | < 2 kg | < 2 kg for antennas that are meter-size. HF antennas (e.g., REASON) are probably going to be much more massive. |
| Surface accuracy/RMS | | Dipole: RF Phase center stable to <1 cm<br>Reflectarray: 1 mm or less | N/A |
| Point and stare | | Possibly | Yes where the s/c moves very slowly and the radar integrates the signal. |
| Location of Use | | Low Earth Orbit, Dipole Like, Distributed Aperture Constellation of Satellites | Between 1-6 AU. (e.g., GEO for close approach Apophis in 2029, Jupiter orbit for Trojan family asteroids, Rosetta met 67P pretty far out there ~5.2 AU). Based on REASON experience: survive a Venus flyby then operate cryogenically. Dipole Like, & Distributed Aperture Constellation |

# 4) SURFACE MOBILE PLATFORM ANTENNAS

## AERIAL AND ROVER

| Requirements | Type | Aerial Mobile Platforms |
|---|---|---|
| Frequency | Notional RF Requirements | 700 MHz |
| Bandwidth | | 800 MHz |
| Gain | | >3 dB |
| Pointing | Notional Mechanical Requirements | Nadir |
| Co-alignment of beams | | TX & RX co-aligned |
| Deployed size range | | 20-50cm |
| Stowed volume | | Under 20 cm x 20 cm x 20 cm |
| Mass | | <600g |
| Moment of Inertia | | As small as possible |
| Location of Use | | Mars |

Mars Helicopter Ground penetrating Radar

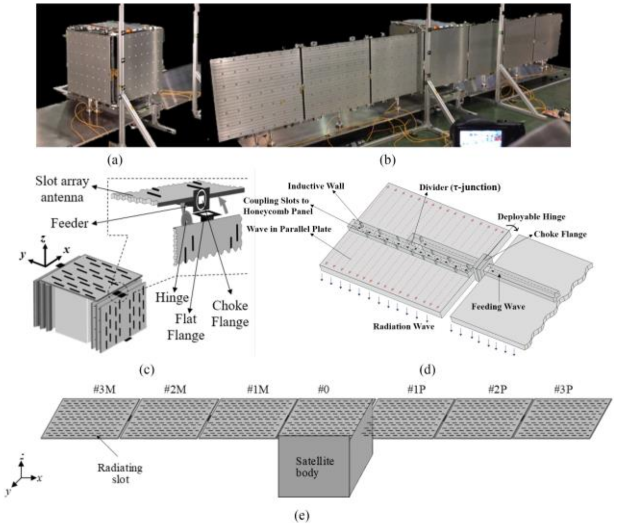
# 5) 0.5 GHZ TO 10 GHZ LONG, NARROW APERTURES

## STV – VEGETATION TOMOGRAPHY RADAR

| | | |
|---|---|---|
| ***Primary Need*** | ***Lightweight compact SAR antenna for distributed remote sensing*** | |
| **Key challenges** | • **High aspect ratio deployable antenna**<br>▪ Gain and efficiency<br>▪ Stowage volume, mass, and cost<br>• **Distributed aperture / formation flying SmallSat constellation radar antenna** | |
| **Key and driving requirements** | ***High Gain Antenna Element*** | |
| | • Frequency | • 1.25 GHz (option: S-band) |
| | • Gain | • >31 dBi (need >83% efficiency) |
| | • Beamwidth (3 dB) | • 1.6 deg / 12 deg |
| | • Polarization | • H, V (option single pol H) |
| | • Transmit power | • <1 kW |
| | • Mass | • 2 kg/m$^2$ |
| | • Stowage | • ESPA Class (TBD) |
| **State-of-the-Art** | Micro-X SAR 4.9 m x 0. 7 m X-band slot array achieved >50% efficiency. | |

### *Key Technologies*

- Distributed aperture radar
- High aspect ratio deployable antennas




**Micro-X SAR Antenna, JAXA, TRL>7**

# 5) 0.5 GHZ TO 10 GHZ LONG, NARROW APERTURES

## SDC – SURFACE DEFORMATION AND CHANGE

| | | |
|---|---|---|
| ***Primary Need*** | ***High Aspect Ratio Deployable L/S/C-Band SAR Antenna for ESPA-class missions (Low Cost NISAR Replacement)*** | |
| **Key challenges** | • **High aspect ratio deployable antenna**<br>▪ Stowage volume and cost<br>▪ Gain and efficiency<br>• **Scanning option** | |
| **Key and driving requirements** | ***Passive Antenna***<br>• Frequency<br>• Aperture (5:1 aspect ratio, typical)<br>• Bandwidth<br>• Power handling<br>• Mass<br>• Stowage | • L-band, S-band, or C-band (TBD)<br>• >15 $m^2$, >30 $m^2$, or >40 $m^2$ (L-band), >5 $m^2$ (S- or C-band)<br>• 85 MHz (L-band), 200 MHz (S-band), 210 MHz (C-band)<br>• 2kW peak<br>• 2 $kg/m^2$ areal mass density<br>• Effective aperture area to stowage volume (incl. feed) ratio > 25 m-1 |
| | ***Electronic Scanning Antenna***<br>• Elevation Scan<br>• Azimuth Scan<br>• Motivation | • -8°, -3°, +2°, and +6° from boresight<br>• -15°, 0°, and +15° beneficial for capturing multiple squint angles<br>• Active Phased Array antennas provide observation flexibility (ScanSAR, TopSAR, Spotlight, etc). |
| **State-of-the-Art** | NISAR Radar | |

***Key Technologies***

- Deployable reflector
- Focal plane array feed
- Scanning passive array
- Electronic Scanned Array

**NISAR 12m Scanning Antenna**

# 5) 0.5GHZ TO 10 GHZ LONG, NARROW APERTURES

## SDC AND STV ANTENNA REQUIREMENTS

| Requirements | Type | SDC | STV |
|---|---|---|---|
| Frequency | Notional RF Requirements | 1.2 – 3.5 GHz | 1 – 10 GHz |
| Bandwidth | | 85-200 MHz | |
| Gain | | > 43 dBi | |
| Losses (emissivity) | | > 50% efficiency | |
| Beamwidth/Side lobes | | 2-12 deg / < -20 dBc | |
| Polarization | | Single - Dual Linear | |
| Pointing | Notional Mechanical Requirements | < 0.1 – 0.2 deg | |
| Co-alignment of beams | | Yes | |
| Deployed size range | | 1 m x 5 m to 2 m x 12 m | 0.8m by 7m |
| Stowed volume | | Surface of ESPA or 0.25x0.25x1.0m | Surface of ESPA or 0.25x0.25x1.0m |
| Mass | | < 30 kg<br>*10-48kg (2 kg/m^2)* | < 20 kg<br>*11kg (2 kg/m^2)* |
| Surface accuracy/RMS | | 4.3mm ($\lambda$/20) | 1.5mm ($\lambda$/20) |
| Location of Use | | Low Earth Orbit | Low Earth Orbit |

# CONCLUDING POINTS

- JPL is pursuing numerous future mission concepts that require new deployable antenna solutions
  - High Frequencies – MM Wave / Sub-MM Wave
    - Conical scan and potentially electronically scanned
  - Low Frequencies – HF/VHF/UHF
  - High Aspect Ratio Reflectors and Arrays – 1-10 GHz
  - Ground Penetrating Radar – Aireborne and Rover
- Some of these categories will require fundamental breakthrough technology
- JPL is actively seeking world-class technology and expertise

# AGENDA FOR WORKSHOP MEETING 1

| Time | Person | Description | Start Time |
|---|---|---|---|
| 15min | Sauder | Overview/Agenda | 8:30 AM |
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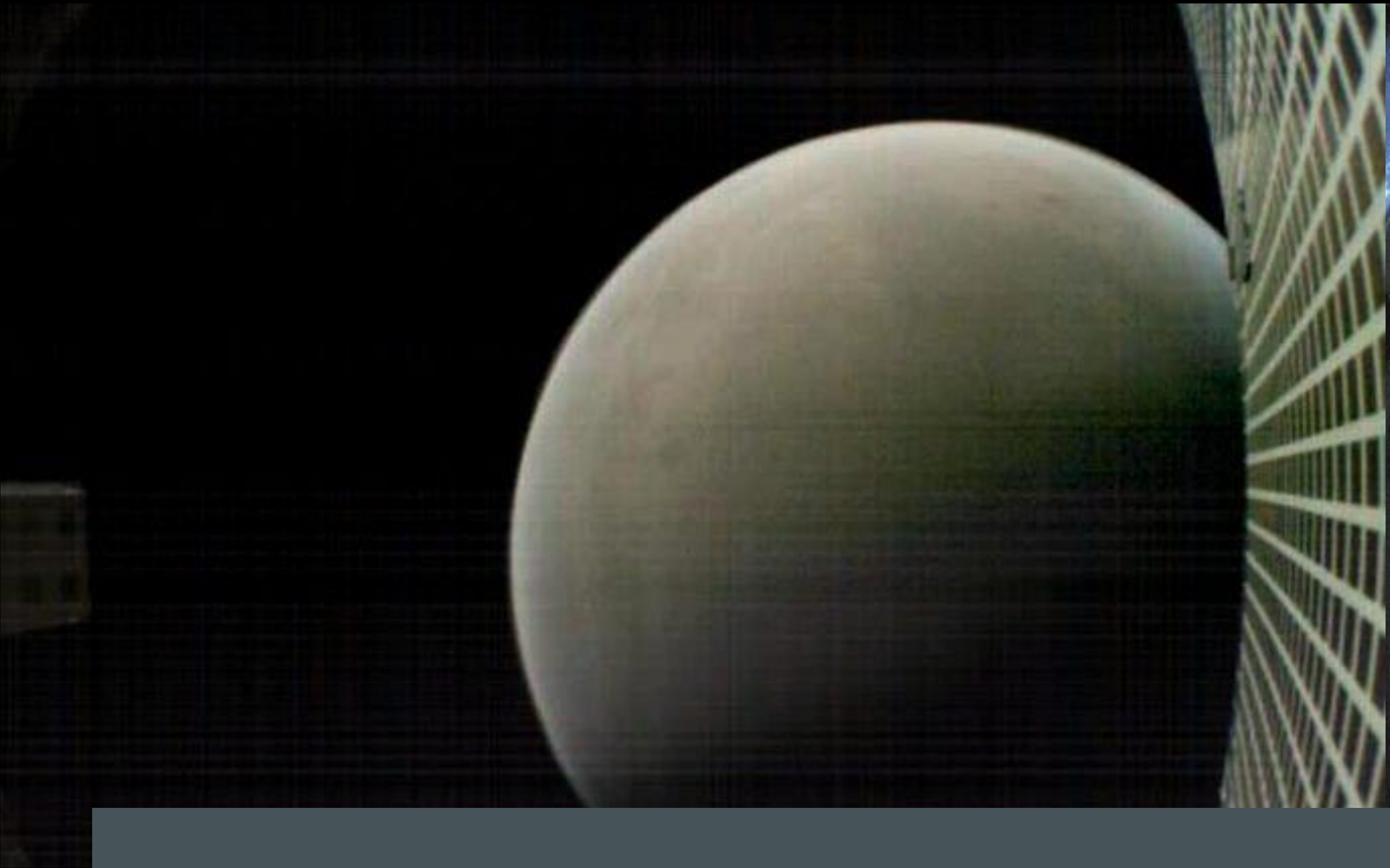

# SMALLSAT DEPLOYABLE ANTENNA WORKSHOP

BREAK: RETURN AT 11:05

Jet Propulsion Laboratory
California Institute of Technology

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# FUNDING MECHANISMS AND THE MAKE VS BUY DECISIONS AT JPL

JASON HYON

Jet Propulsion Laboratory
California Institute of Technology

## 6 PARTNERSHIP STRATEGY

**Consistent with the NASA Strategic Plan and in coordination with the NASA's Office of International and Interagency Relations (OIIR), JPL strategy is to actively engage other NASA centers, national laboratories, industry, and academia, as well as international partners to achieve its vision and pursue its scientific quests for the benefit of humankind.**

### NASA CENTERS

JPL is part of the NASA family of field centers, managed by Caltech, as the only NASA Federally Funded Research and Development Center (FFRDC). JPL strategy is to actively engage other NASA centers in a strategic partnership relationship, and favor teaming over competing wherever possible. JPL strategy is also to offer support to other NASA centers as they pursue their own strategic goals. JPL will foster and support a culture of One NASA.

### NATIONAL LABORATORIES

JPL strategy is to partner with national laboratories and other Federally Funded Research and Development Centers (FFRDCs) that have synergistic and complementary core competencies, such as the Johns Hopkins University Applied Physics Laboratory, Sandia National Laboratories, MIT Lincoln Laboratory, and Southwest Research Institute, among others.



**Draft - in progress**

### ACADEMIA

JPL strategy is to invest in collaborations with universities across the country and the rest of the world. JPL maintains a Strategic University Research Partnership (SURP) program that supports research at universities where JPL has a critical mass of ongoing work. JPL supports an active postdoctoral program, faculty exchanges, and distinguished visiting scientists.

### COMMERCIAL

JPL strategy is to actively consider the use of public-private partnerships in pursuit of our scientific goals wherever possible. This includes the opportunity to learn from and leverage the fast growing New Space industry of innovative companies. JPL strategy is to make these partnerships a two-way opportunity: for JPL to commercialize enabling space technologies and know-how, and to learn new ways of doing business in a more nimble and agile way.

### INTERNATIONAL

NASA and JPL realize that many of our science and exploration goals cannot be achieved alone. International partnerships are not only important but are in many cases enabling. In coordination with NASA's OIIR, JPL strategy is to actively engage in the formulation of new mission opportunities with our international partners, such as the European Space Agency (ESA), the French Space Agency (CNES), the German Space Agency (DLR), the Italian Space Agency (ASI), the Indian Space Research Organisation (ISRO), the Japanese Aerospace Exploration Agency (JAXA), and others. This includes the opportunity to perform joint technology demonstration missions in space.

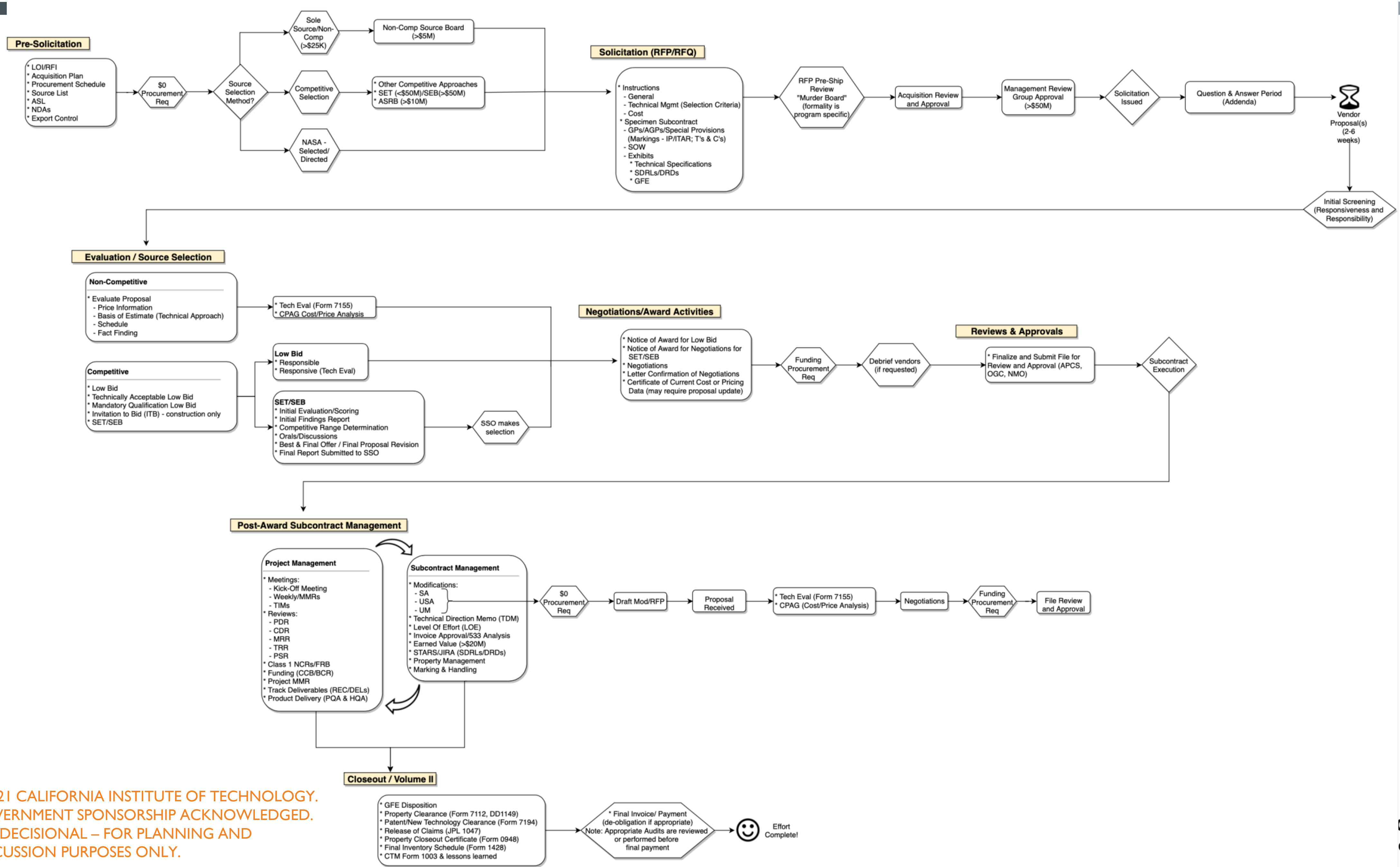


**Draft - in progress**

# OPPORTUNITIES

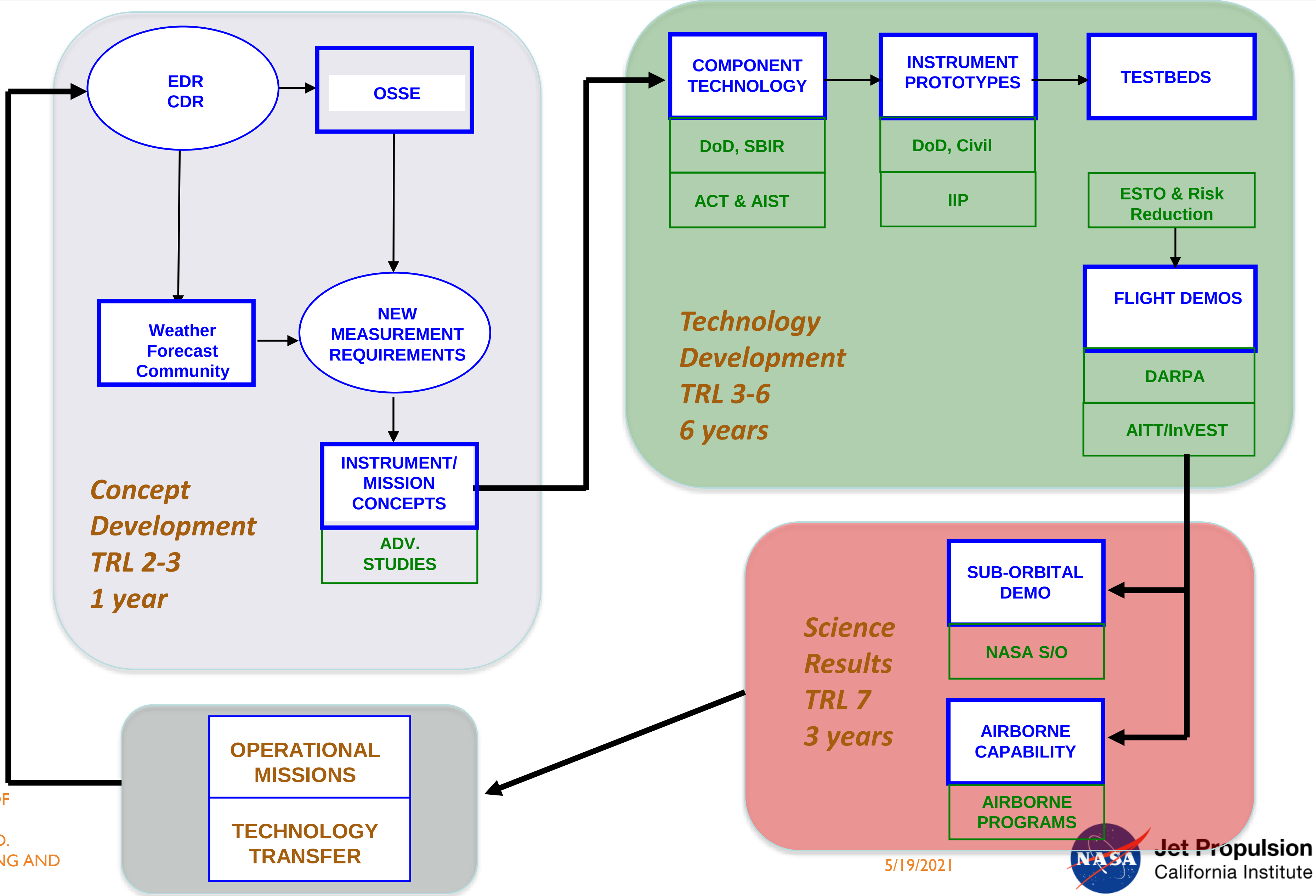
- Well established specification – RFP
  - Proven capabilities – Sole sourced or competed
  - Good to know ahead of your capability
  - Fixed price and/or cost plus
- Research and development partnership
  - NASA ROSES Earth and Planetary - ACT/IIP, PICASSO
  - SBIR/STTR
  - STMD NAIC
  - NASA AO – TRL 6/5 at submission
- Strategic JPL internal investment
  - Cross directorate infusion
- Space Act – Technology transfer

# Acquisition Process Flow for Subcontracts

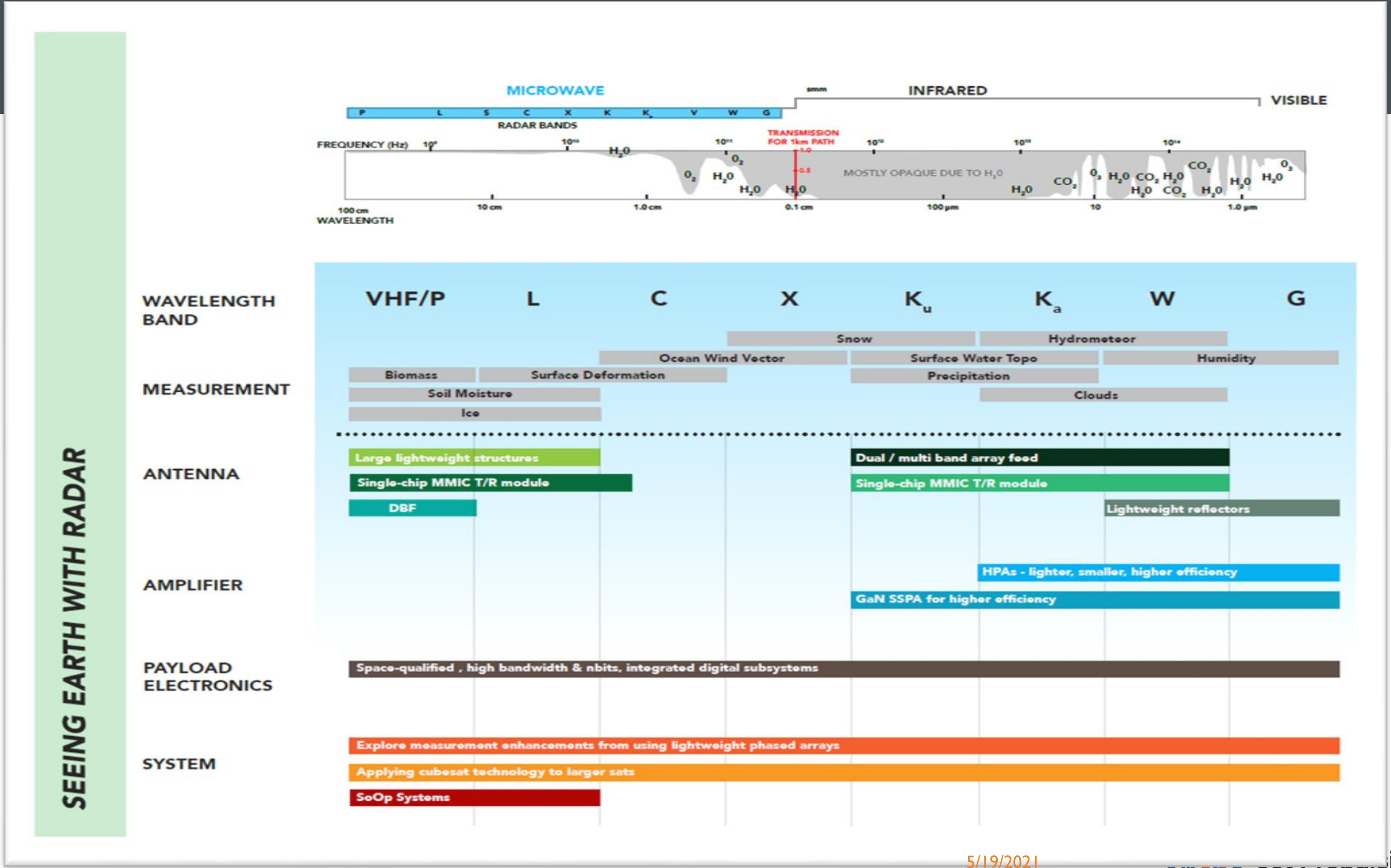


# Established Instrument Development Cycle

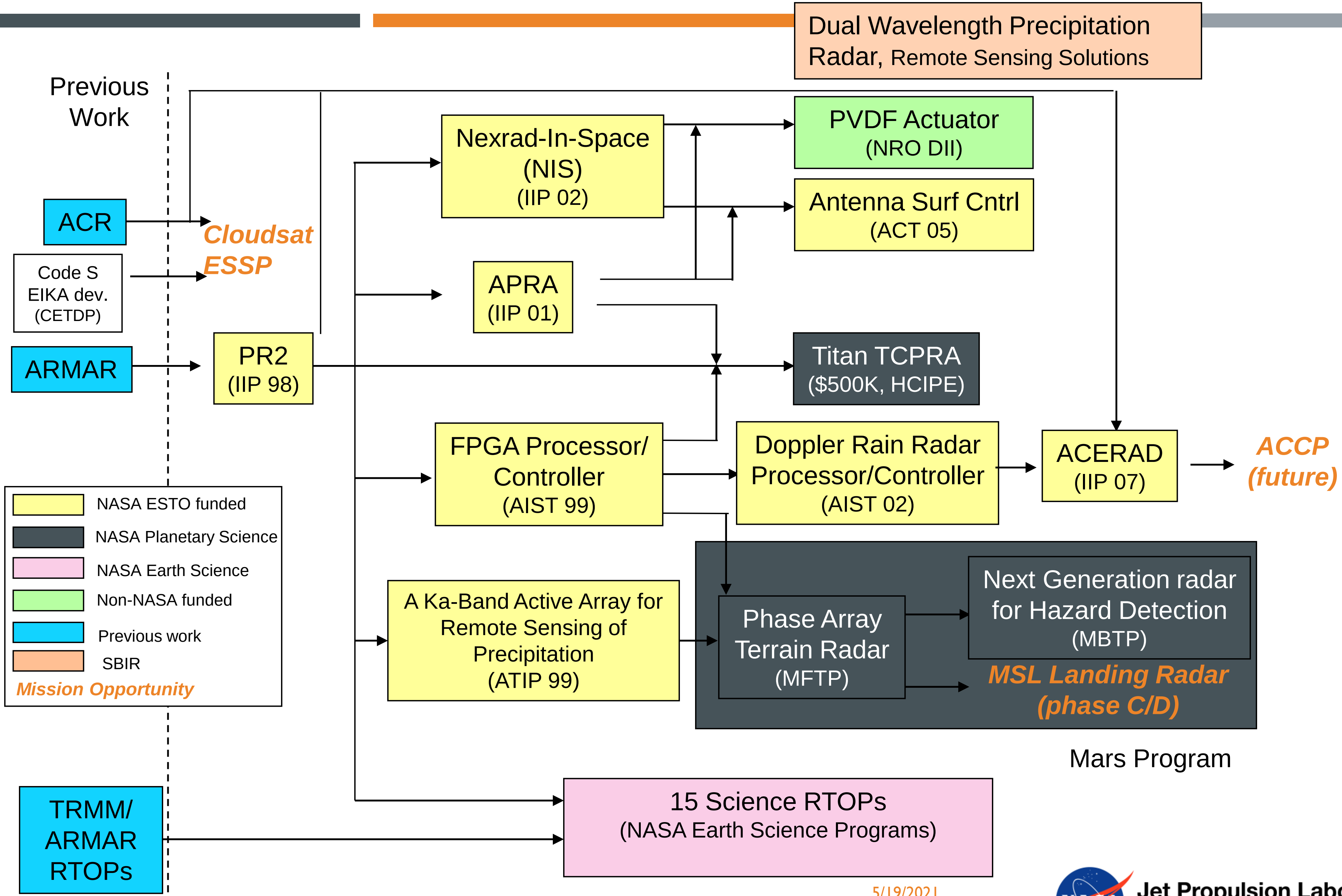
## Through NASA ESTO + Reimbursable



# The Radar Technology Needs Landscape



# Technology Investment for Atmospheric Radar



# MAKE VS. BUY

- Antenna technology is an enabling capability that JPL values as a core capability
  - Make for research
    - Opportunity for partnership, joint development, tech transfer
    - Instrument and spacecraft driven designs require internal engagement
    - Groups in RF design, deployment design, mechanical/thermal, V&V
  - Buy for flight antenna, mostly
    - Subsystem or full antenna
    - Good to inform our POC with your progress
    - Seminars, informal communication, model verification

JPL welcomes innovative ideas in advancing technologies to benefit life on Earth and find life elsewhere.

Please join us and We will assist you in infusing your technologies.

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# SMALLSAT DEPLOYABLE ANTENNA WORKSHOP

# TECHNOLOGY TRANSFER PERSPECTIVES

DAN BRODERICK, JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY

MAY 19, 2021



The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.

Jet Propulsion Laboratory
California Institute of Technology

# JET PROPULSION LABORATORY

- Operated by the California Institute of Technology
- Bayh Dole applies, Caltech may elect title to patents that arise from JPL research and development
- National Laboratories are governed by the Stevenson-Wydler Technology Innovation Act of 1980
- "..technology transfer, consistent with mission responsibilities, is a responsibility of each laboratory science and engineering professional."

# PATENTS - BAYH-DOLE ACT

University Contractor (Caltech is the Contractor for JPL) may elect to retain title to inventions developed under federally-funded research programs (1980)

U.S.Government retains a royalty-free nonexclusive license to make, use, and have made by its contractors

Exclusive licensee must substantially manufacture in the U.S. (can be waived if cannot find a U.S. mfr)

University must give preference to small businesses

# EFFICIENT LICENSING PROCESS

- Industry reps encouraged to work with researchers directly to discuss technology
- Efficient Licensing Process
  - Licensing staff has full authority to negotiate license
  - One contact person
  - High degree of flexibility to adapt to a multitude of business models
  - No legal review required, at discretion of licensing professional

# POINTS OF NEGOTIATION FOR LICENSING

- Exclusivity
- Field of Use
- Sublicensing (rights and royalties)
- Royalty Rate, Minimum Royalty
- Payment of Patent Expenses
- Litigation rights
- Equity, Participation Rights in Future Financings
- Technical and Commercial Milestones
- Warranties, Indemnity
- Term and Termination

# EXCLUSIVE LICENSE

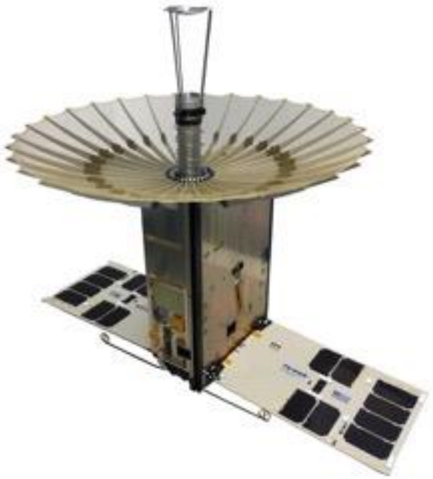
- Technology is licensed to only one company
- May have a Field of Use (i.e. space or terrestrial)
- Caltech/JPL and U.S. Government still maintain reserved rights
  - U.S. Government can make, use, and have made by its contractors
  - Caltech/JPL for research and Government use
- Typically comes with higher licensing fees and higher minimum royalties
- Typically has more stringent performance milestones non-exclusive license (alpha and beta prototypes, first sale, launch …)

# NONEXCLUSIVE LICENSE

- Technology may be licensed to multiple companies
- May have Field of Use
- Typically lower licensing fees and lower minimum royalties
- May have performance milestones

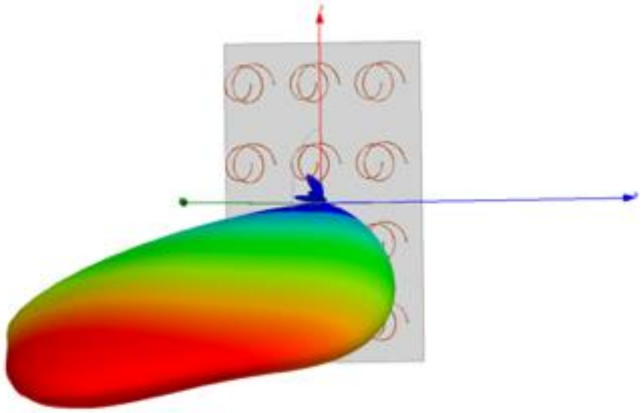
# KAPDA HIGH GAIN CUBESAT ANTENNA

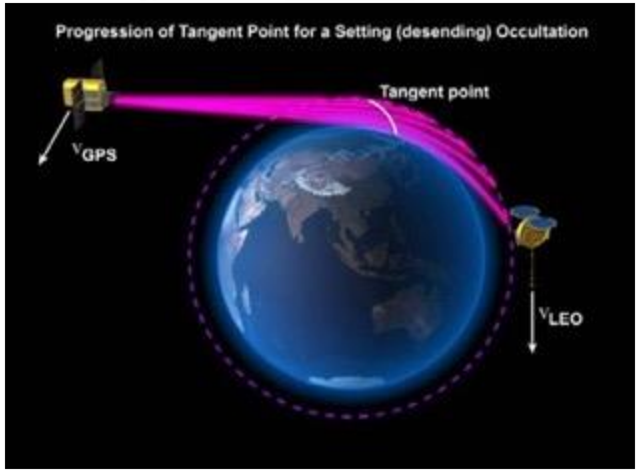
- Tendeg LLC is developing and building a novel space deployable antenna
- Exclusive license to Tendeg from Caltech/JPL
- NASA JPL RainCube flight in May 2018 (fully tested)
- KaPDA (26.5 -40 Ghz) cubesat antenna (applications to 5G)
  - 42.7 dB Gain
  - Can be made to operate at C, X, Ku, K, and Q bands



# PHASED ANTENNA ARRAY FOR GLOBAL NAVIGATION SATELLITE SYSTEM SIGNALS

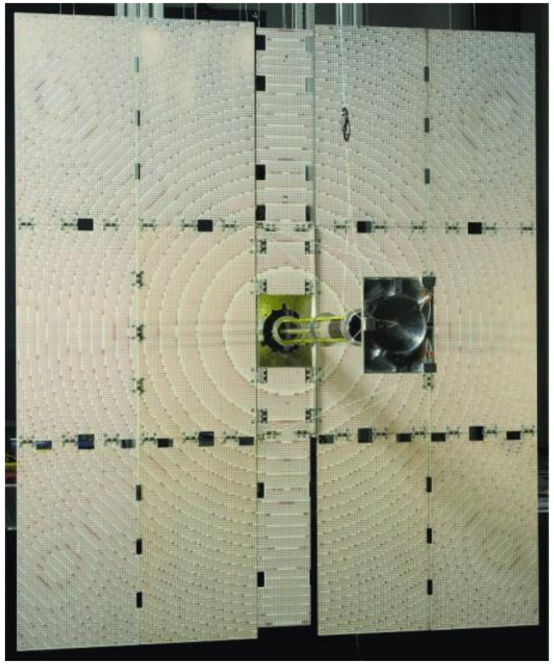
- Steerable 12-15 element phased array
- Array of helical elements and low-loss feed network designed to provide proper phasing and impedance matching between antennas
- Applicable to radio occultation
- Each individual element electrically phased in a way that synthesizes a final directivity patten whose peak gains are distributed along the limb of the Earth
- 18 dBic gain at GPS and 16 dBic L1/L2/L5 gain
- Patent 9,190,724

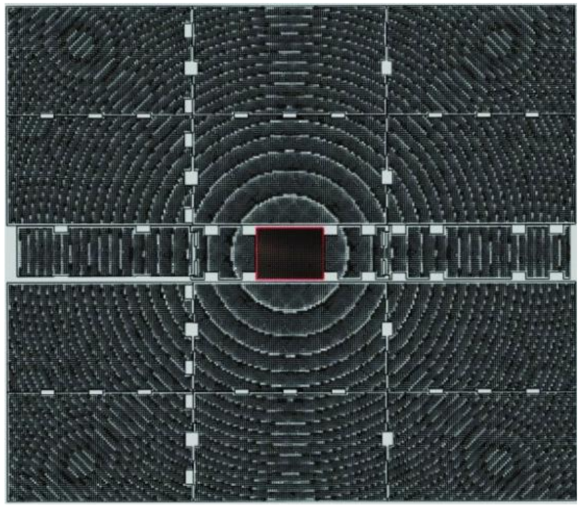




# DEPLOYABLE REFLECTARRAY ANTENNA

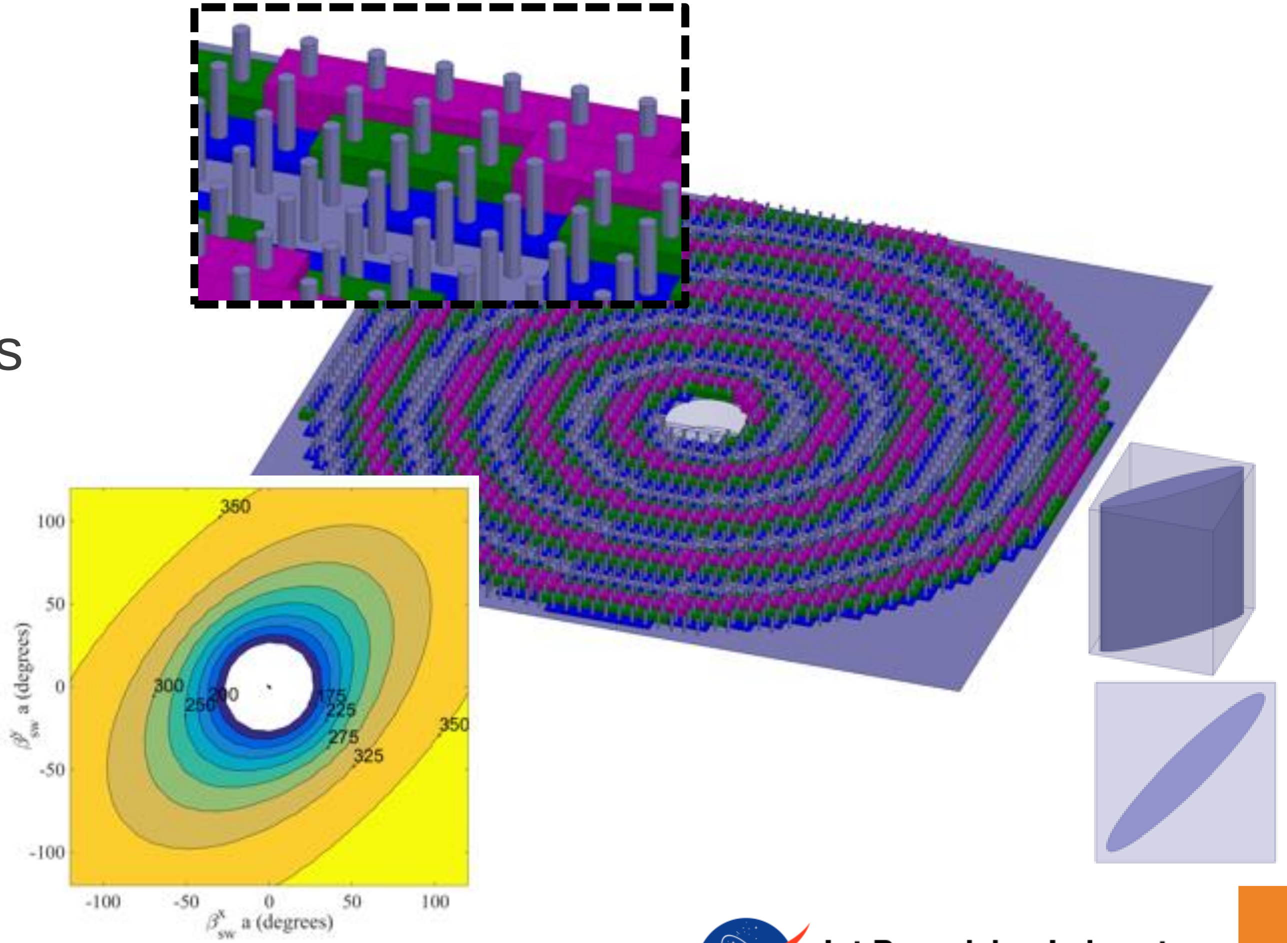
- Designed to fit 6U class CubeSat
- Largest Ka band antenna for 6U
- 92.25 cm x 1049.2 cm flat reflector
- 322 x 366 elements
- 0.7 focal distance
- Can be fabricated to meet on-orbit thermal demands
- 35.75 Ghz, gain of 47.4 dBi
- Panels deploy on orbit
- Gain 48.2 dBi achievable
- Patent 10,276,926





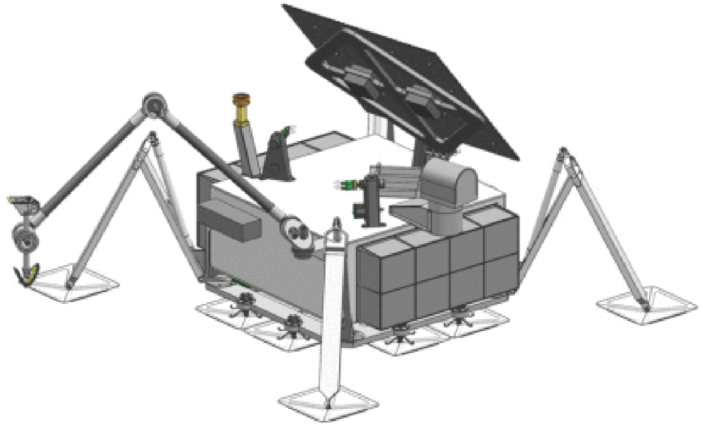
# LOW PROFILE AND HIGH GAIN MODULATED METASURFACE ANTENNAS GHZ TO THZ

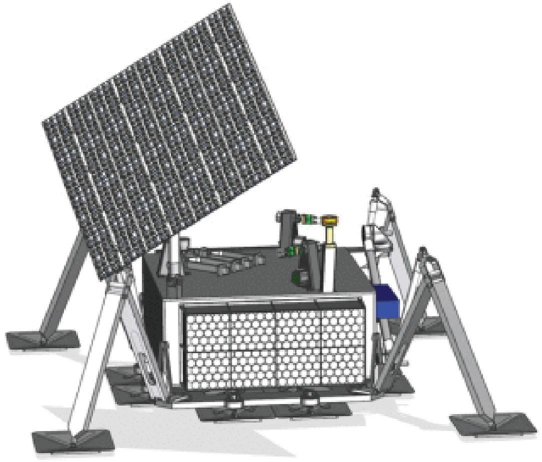
- Modulated metasurface antenna
- Metasurface fabricated from from metalized cylinders on a ground plane
- Can operate at GHz or THz frequencies
- High directivity
- Can be fabricated from Si wafer using DRIE
- Patent 10,418,72



# HIGH EFFICIENCY DUAL BAND CIRCULARLY POLARIZED ANTENNA FOR HARSH ENVIRONMENT TELECOM

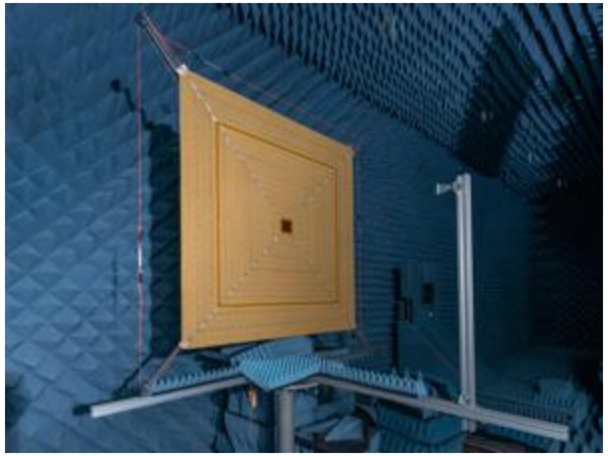
- All metal antenna concept:
  - Consists of 4 panels of 16x16 patch array.
  - The patch element covers both Rx and Tx frequency band
- Mass estimate: 10kg
- The design has heritage from Juno
- Antenna efficiency: 80%
- Patent 10,680,345

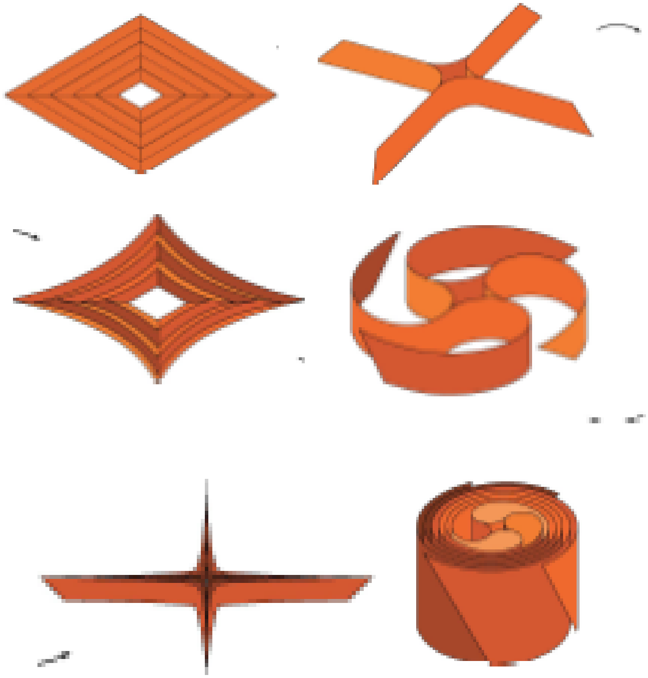




# LARGE APERTURE DEPLOYABLE REFLECTARRY ANTENNA

- Reflectarray antenna on a thin ply composite laminate
- 1.5 meter by 1.5 meter antenna can be stowed compactly in a 6U CubeSat
- Folded prototype produced a peak gain of 39.6 db at 8.4 GHz
- Patent recently allowed, pub. 2019-0393603





# QUESTIONS, CONTACT

- https://ott.jpl.nasa.gov
- daniel.f.broderick@jpl.nasa.gov

Dare Mighty Things

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# GUIDANCE ON PROPOSING TO NASA SBIR SOLICITATIONS (HOW TO PROPOSE SBIR'S FOR SOLUTIONS TO TECHNOLOGY GAPS)

CAROL LEWIS, JPL SBIR/STTR MANAGER

Jet Propulsion Laboratory
California Institute of Technology

# BACKGROUND

- In June 2018, I had the opportunity to represent NASA SBIR/STTR on the U. S. Small Business Administration (SBA) Eastern SBIR Road Tour. The Road Tour is a collaborative outreach effort which connects entrepreneurs working on advanced technologies with Federal agencies' SBIR/STTR programs. This included participation on two particularly relevant panels: Inside the Head of an Evaluator, and Lessons Learned/ Common Mistakes.
- The event lead, Brittany Sickler (Senior Innovation Policy Advisor, SBIR/STTR, Office of Investment and Innovation, SBA) provided us with an excellent written framework for these discussions.
- Because this SBA material is universally applicable and timely, I have adapted their framework to this presentation. *(Credit to Brittany Stickler and the SBA for this foundational material).*

# INSIDE THE HEAD OF AN EVALUATOR (1/3)

*The most common and avoidable mistakes made by applicants, and candid insights for preparing more competitive proposals.*

- Importance of following the Solicitation instructions (Government solicitations are defined by rules, volume limits, etc.)
  - Are there road maps, checklists, or guidelines that help applicants navigate technical requirements?
  - Are there opportunities or system flags that can give applicants an opportunity to correct or update their proposals if needed?
  - Every agency needs to follow the overall SBA framework, but the implementation details are up to the individual agency. There may be significant variations between agencies, so always read the Solicitation in its entirety.

# INSIDE THE HEAD OF AN EVALUATOR (2/3)

*The most common and avoidable mistakes made by applicants, and candid insights for preparing more competitive proposals.*

- Proposal Preparation and Evaluation Process – what to avoid
  - When evaluating a team, is it obvious when the PI is spread too thin? What if there's no subject matter expert (SME) within the technical area?
  - Do we see applicants typically write too much about commercialization?  Or too little?
  - How often does a budget miscalculation come back to haunt a company?
  - There are a variety of definitions for "innovation", how does a firm  make sure they're addressing the right thing in their proposal?
  - Who should the firm view as their reader or evaluator?  Is it possible to be too technical?

# INSIDE THE HEAD OF AN EVALUATOR (3/3)

*The most common and avoidable mistakes made by applicants, and candid insights for preparing more competitive proposals.*

- Obtaining Feedback
  - If an applicant is unsuccessful, are there opportunities (formally or informally) to learn about their weaknesses and strengths?
  - Are there example proposals or other resources to help the audience prepare more competitive proposals?

# LESSONS LEARNED AND COMMON MISTAKES (1/3)

*The most common and avoidable mistakes made by applicants, and candid insights for preparing more competitive proposals.*

- Government solicitations are often defined by rules, volume limits, company registrations, etc.
  - What's the most common technical rule error, that applicants make when applying to the NASA SBIR/STTR program?
  - What other common errors do we typically see?
  - Consequences of errors can range from relatively minor to fatal flaws, and may include:
    - Administrative screening out (proposal fatally flawed)
    - Technical screening out (proposal nonresponsive)
    - Poor technical reviews
    - Poor programmatic rankings

# LESSONS LEARNED AND COMMON MISTAKES (2/3)

*The most common and avoidable mistakes made by applicants, and candid insights for preparing more competitive proposals.*

- Proposal Evaluation / Review Process – Lessons to share so firms can avoid errors in:
  - The Construction/Qualification of their team (e.g., PI spread too thin, not a SME within the technical area, etc.)
  - Commercialization Planning/Strategy
  - Proposal Budget/Scope
  - Technical Approach and/or Innovation

# LESSONS LEARNED AND COMMON MISTAKES (3/3)

*The most common and avoidable mistakes made by applicants, and candid insights for preparing more competitive proposals.*

- Telling the Story – SBIR and STTR are funded through a written Solicitation Process:
  - What makes a proposal weak and how can attendees avoid these issues?
  - Note NASA's review process is primarily internally driven, except for Phase II commercialization which utilizes external peer review.
  - If a firm is applying to our program, whom should they view as their "audience or customer?"
    - Does the emphasis on innovation, versus commercialization, versus team qualifications change, given who is the customer or audience?

# DEBRIEFINGS AND FEEDBACK

- If an applicant is unsuccessful, are there opportunities, either formally or informally – to learn about their weaknesses and strengths?
  - NASA SBIR has a formal proposal debriefing process which is described in the Solicitation. Written debriefings are automatically provided to Phase I firms but must be requested by Phase II firms.

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# WHO TO TALK TO AT JPL

JONATHAN SAUDER/RICHARD HODGES

Jet Propulsion Laboratory
California Institute of Technology

# WHO TO TALK TO AT JPL

Antenna RF

- Paula Brown
  - Paula.R.Brown@jpl.nasa.gov
  - Technical Group Supervisor for Spacecraft Antennas

Mechanical

- Case Bradford
  - Samuel.C.Bradford@jpl.nasa.gov
  - Technical Group Supervisor for Advanced Deployable Structures Group
- Jonathan Sauder
  - jsauder@jpl.nasa.gov
  - Mechanical Systems for Deployables, Mesh Antennas

Programmatic

- SBIR Office
  - Carol.R.Lewis@jpl.nasa.gov
  - mark.h.davidson@jpl.nasa.gov
- Office of Technology Transfer at JPL
  - Daniel.F.Broderick@jpl.nasa.gov

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# NEXT STEPS FOR CONTINUING THE CONVERSATION WITH JPL

JONATHAN SAUDER

Jet Propulsion Laboratory
California Institute of Technology

# THIS WAS THE FIRST OF TWO SETS OF MEETINGS

- Today: Workshop Meeting 1
  - Goal 1: Communicate current JPL understanding of technology gaps and requirements associated with deployable antenna
  - Goal 2: Communicate ways potential partners can collaborate with JPL.
  - Attendees: JPL → Potential Partners
- June 2$^{nd}$ to June 18$^{th}$: Workshop Meetings 2
  - Goal: Have potential partners present their capabilities to JPL, and discuss mechanisms for evolving the technologies to meet JPL needs.
  - Attendees: One Potential Partner → JPL (per meeting)
    - Each potential partner with relevant technologies meets separately with JPL

# AGENDA FOR WORKSHOP MEETINGS 2

| Presenter | Description |
|---|---|
| Sauder | Overview/Introductions |
| Outside Organization | Presentation on Capabilities, and Relevance to JPL |
| ALL | Q&A & Discussion |
| JPL Panel | Formal Feedback from JPL |
| ALL | Ask Us Anything Style Session |

Time will be scaled pending feedback from the partner, and relevance to current missions.

# WORKSHOP MEETINGS 2

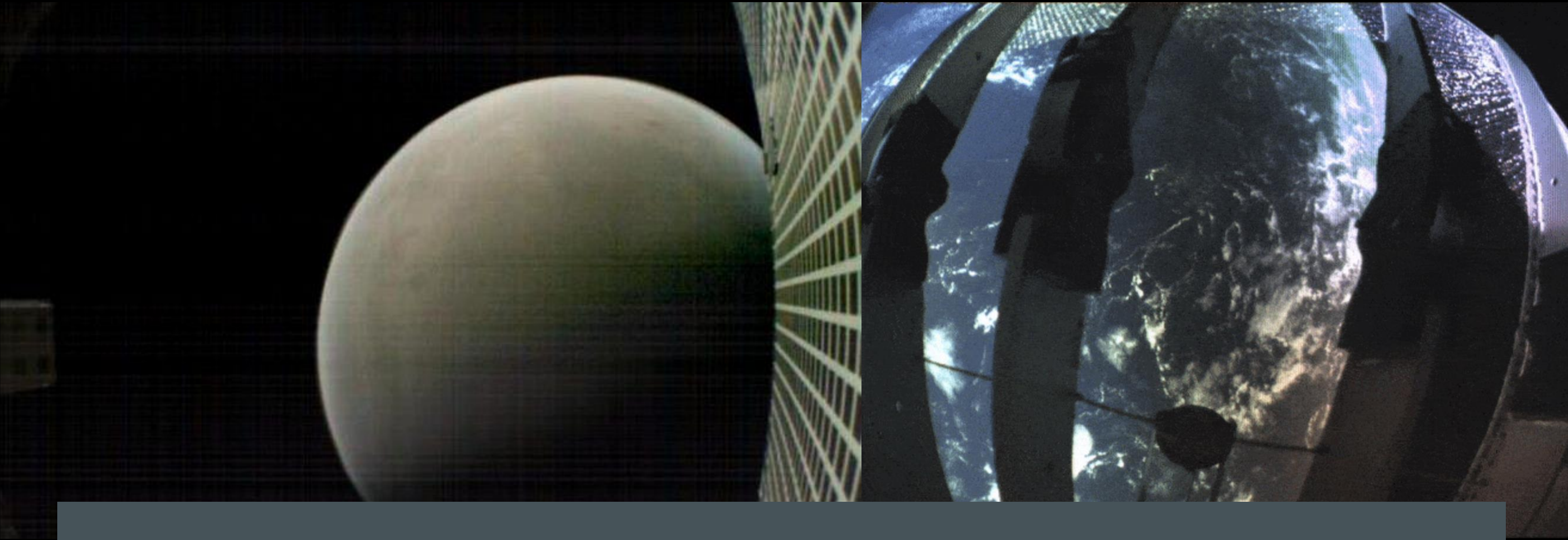
- If you have solutions to the gaps presented here, please send an email to jsauder@.jpl.nasa.gov
  - In your email, please include:
    - Which of the presented gaps (1 through 5) you have solutions for, and the number of technologies you would to talk for each gap.
    - References to any publications, etc. on your solutions to those gaps.
    - 3-5 windows of time between June 3rd to June 18th, when you we be available to meet.
      - Please provide times in PDST (Pacific)
  - Note: JPL has a standard NDA, which can be processed in ~1 week. Any company specific NDA's often requires months.
- The more relevant information you can send me ahead of time, the more I can get the right parties in the room.
- Send to Jonathan by COB 5/26

# SUMMARY OF CURRENT GAPS

1. Reflectors suited for mm/sub-mm (70GHz and higher), includes lower frequencies as well
2. Ultra-low-mass, 2-6m large aperture rotating 60-90 GHz reflectors and Ultra-low-mass, 2-6m large aperture rotating 90 GHz+ reflectors
3. Large broadband antennas for low-frequencies (0.01-1 GHz) monolithic
4. Surface Mobile Platform Antennas
5. 500MHz to 30 GHz (P through Ku band) Long, Narrow Apertures

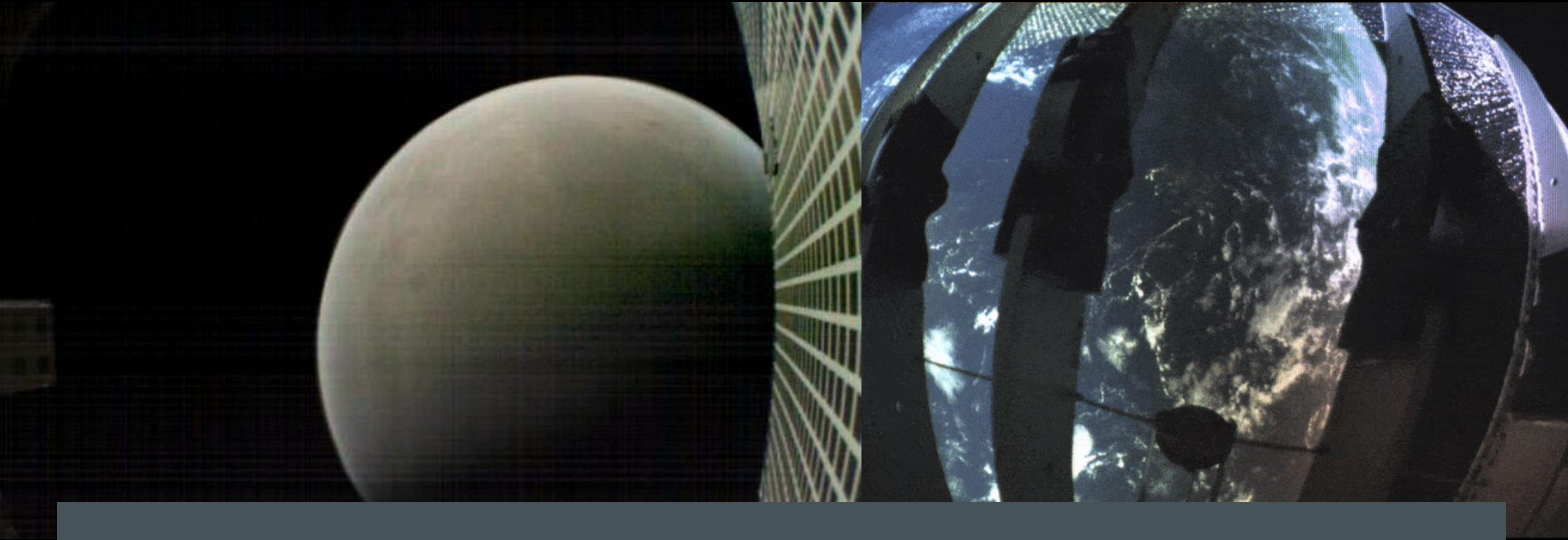
# AGENDA FOR WORKSHOP MEETING 1

| Time | Person | Description | Start Time |
|---|---|---|---|
| 15min | Sauder | Overview/Agenda | 8:30 AM |
| 45min | Haynes/ Cooper/Rodriguez Monje/ Beauchamp/ Brown | Instrument Aspirations | 8:45 AM |
| 15min | P. Brown | Overview of Current JPL Antenna Capabilities | 9:30 AM |
| 20min | Sauder | Current Technology Gaps for Mission Needs | 9:45 AM |
| 20min | Hodges | Derived Antenna Requirements | 10:05 AM |
| 30min | Group | Technical Question and Answer | 10:25 AM |
| 10min | | BREAK | 10:55 AM |
| 20min | Hyon | Funding Mechanisms and the Make vs Buy Decisions at JPL | 11:05 AM |
| 20min | Broderick | Technology transfer opportunities with JPL | 11:25 AM |
| 30min | Lewis | How to propose SBIR's for solutions to the gaps | 11:45 AM |
| 5min | Sauder/Hodges | Who to talk to at JPL. Finding the right SME | 12:15 PM |
| 10min | Sauder | Next Steps for Continuing the Conversation with JPL | 12:20 PM |
| 30min | Group | Programmatic Question and Answer | 12:30 PM |
| **4.5hours** | **Total Time** | | |



# SMALLSAT DEPLOYABLE ANTENNA WORKSHOP

QUESTIONS?



# SMALLSAT DEPLOYABLE ANTENNA WORKSHOP

THANK YOU FOR ATTENDING